THE PRESIDENT'S BADGE OF OFFICE

Presented to the Society

BY MR. GEORGE BURT, HONORARY SECRETARY AND TREASURER

NOVEMBER 22, 1900

SOCIETY OF ENGINEERS

ESTABLISHED MAY 1854

Journal and

TRANSACTIONS FOR 1900

AND

GENERAL INDEX, 1857 TO 1900

EDITED BY

PERRY F. NURSEY

SECRETARY

London
E. & F. N. SPON, LTD., 125 STRAND
New York
SPON & CHAMBERLAIN, 12 CORTLANDT STREET
1901

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PAPERS AND PREMIUMS.

THE Council of the Society of Engineers invites original communications from Members and Associates, as well as from gentlemen who do not belong to the Society, on subjects connected with any branch of Engineering.

For any papers that may be considered sufficiently meritorious the Council may at discretion award one or other of the following Premiums, viz.:—

1. THE PRESIDENT'S PREMIUM, given annually by the President, and consisting of a Gold Medal of the value of Five Guineas.

2. THE BESSEMER PREMIUM, provided for annually by the late Sir Henry Bessemer, F.R.S., Honorary Member, of the value of Five Guineas.

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The number and value of the Society's Premiums are decided by the Council according to the number of meritorious papers read during the year.

By the Rules of the Society, Members of Council are disqualified from receiving Premiums for Papers.

PREMIUMS FOR 1900.

AT a Meeting of the Society, held on February 4, 1901, the following Premiums were presented, viz.:—

The President's Gold Medal to:

HENRY C. H. SHENTON, for his paper on Recent Practice in Sewage Disposal.

The Bessemer Premium of books to:

RICHARD F. GRANTHAM, for his paper on The Closing of Breaches in Sea and River Embankments.

A Society's Premium of books to:

C. ROUS-MARTEN, for his paper on English and French Compound Locomotives.

A Society's Premium of books to:

ROBERT HENDERSON, for his paper on Paper-Making Machinery.

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PLACE OF MEETING.
THE ROYAL UNITED SERVICE INSTITUTION, WHITEHALL.

1901

TRANSACTIONS, &c.

February 5th, 1900.

INAUGURAL ADDRESS.

By HENRY O'CONNOR, President.

In occupying, for the first time, the chair to which you have done me the honour of electing me, you will perhaps not think me less appreciative of your goodness if I confess to you that my first and strongest feeling is one of diffidence, as I venture to take up the succession to a long line of presidents whose talents and reputation, while conferring eminent distinction on the office, have at the same time rendered it all the more difficult to worthily fill. But while I dare not hope to rival my predecessors in fitness for the chair, it is with the more reason that I now thank you most sincerely for the great honour you have conferred upon me, and express the hope that I may succeed, during my term of office, in showing my sense of that honour by strenuously endeavouring to maintain the worthy traditions of the office, and to further the interests of the Society.

It will be a matter of gratification to all of us to know that our Society continues to prosper both numerically and in a financial sense. During the past year we have lost from various causes 25 members in all, but the new members and associates elected during the same period numbered 49, the net addition during 1899 being thus 24, a figure which enables us to begin the year 1900 with a membership of exactly 500.

Regarding our financial position, we have now, in addition to a balance at credit of current account, the sum of 250*l.* at interest on deposit, over and above our permanent investments.

It has been a matter of much regret to me, and of no little personal loss, that my removal some years ago from this city to "the grey Metropolis of the North" has since then deprived

me, in a great measure, of the privilege which I made regular use of while resident in London, of attending the meetings of the Society and being present at those visits to places of technical interest which form so useful a variation after the winter months are over. I hope, however, to be much more fortunate this year, and as regards last year, I am glad to know that the papers read have come well abreast of those given in previous sessions, both in choice of subject and ability of treatment. My predecessor, Mr. J. Corry Fell, in his excellent Inaugural Address delivered in February last reviewed the question of the protection of inventions by patents in engineering practice, and further gave a short summary of the advances made of late years in various departments of general engineering. Following upon this we had in March a highly interesting paper by Mr. E. Wynter Wagstaff, A.M.Inst.C.E. on "The Shan Hill country and the Mandalay railway." He described the very considerable difficulties experienced in the making of the survey, not only due to the nature of the ground but also owing to the trouble with the native labour, some 90 persons in all being engaged with special transport service of about 150 pack bullocks. The two or three surveys of the Gokteik Gorge were detailed, these being made to allow of either an 8 per cent. rack line, or a 4 per cent. or $2\frac{1}{2}$ per cent. adhesion line. For this paper Mr. Wagstaff was awarded the President's Gold Medal.

The next paper, in April, was by Mr. Ewart C. Amos, M.I.M.E. on "Machine tools," when he showed the considerable advantage in the employment of modern tools with ball thrust, hollow spindles and cut-toothed gearing. He described modern lathes and machinery for drilling, boring, milling, planing, shaping, slotting, keyway-cutting, punching and shearing, plate bending, metal sawing, and forging and welding; showing that in the long run good tools were cheaper than the so-called cheap tools, although higher in the first cost. This paper obtained one of the Society's premiums. The May meeting was devoted to a paper on "Petroleum motor vehicles" by Mr. James D. Roots. The different stages of progress of the various types of petroleum road vehicles were shown in approximate chronological order, and the developments pointed out. A comparative statement of the running costs of petroleum oil and petroleum spirit motors was given, the author claiming that the latter showed six times the fuel cost per brake horse-power of the former. The paper was illustrated with some 54 views of motor vehicles.

On the 5th June Mr. R. G. Allanson-Winn read a paper on "Foreshore protection, with special reference to the Case system of groyning," for which he was awarded the Bessemer

Premium. The author pointed out the considerable loss of material on the east coast of Yorkshire, and stated that in all probability during the coming century the Wash would be silted up to such an extent as to add 100,000 acres of land in that vicinity. The Case system of low groyning was described, whereby the shore was built up to its required curved angle of repose, principally through the action of the sea itself. "Photographic Surveying" was treated on by Mr. J. Bridges Lee, M.A., F.G.S. at the October meeting, when the author's methods and improvements in the apparatus for carrying out this work were shown and described, and the advantages claimed for the system fully discussed.

The November meeting brought forward Mr. Cowper-Cole's paper on "The electrolytic treatment of complex sulphide ores." A number of processes were described for the distilling of zinc from its ores, and it was pointed out that about 16 per cent. of the metal was not extracted from the ore, and that 10 tons of coal were required to produce 1 ton of zinc by the present process. The author then detailed a number of experiments made by himself on sulphide ores, and showed a number of specimens of the crude ores and their products.

Mr. Gordon Harris, A.M.Inst.C.E., M.I.M.E., read a paper on 4th December on "Water supply to country mansions and estates," and described various methods of obtaining water for house, farm, and fire-extinguishing purposes, giving the cost of pumping by hand labour, horse-power, gas engine, small steam pump, and boiler, oil engine and pump, and electrically driven pump. Mr. Harris was awarded a Society's premium for this paper.

With reference to the visits that have taken place during the year, you will permit me, as is customary, to recapitulate these in brief detail.

On the 14th June the visit was to the London station and goods depôt of the Great Central Railway at Marylebone, when the members present saw the passenger station with its numerous offices, refreshment rooms, &c., and the platforms then completed, which were only one-half the ultimate extent contemplated. The goods station was next examined, with its machinery of all kinds worked by hydraulic power, and the rails laid at such a level as to afford convenient access to the adjacent streets.

On the 18th July a well-attended visit was made to the Folkestone pier extension works and the Dover colliery works. At the former works where the existing pier is being extended in all some 900 feet, the visitors were shown the elaborate arrangements for the manufacture of the concrete blocks of

which the extension consists, and the general details of the procedure were pointed out. At the colliery works the three pits were examined, which have been carried down respectively to 520 feet, 605 feet, and 454 feet, and tunnels are being now worked to connect the two latter pits, while new and powerful pumping machinery is being provided to assist that already in operation.

The third visit was to the machine works of the Wicks Rotary Type-Casting Company, and the works of Bischof's White Lead Syndicate on the 20th September, when the very elaborate and delicate machinery for the casting of type at the rate, if necessary, of 60,000 an hour, was examined, as well as the beautiful and accurate machines for the making of this apparatus which requires to be adjusted to the ten-thousandth part of an inch. The Wicks type-setting machine was also seen. The Bischof process of manufacturing white lead, which was afterwards examined, is said to have many advantages in that it is comparatively innocuous, whilst the conversion of the metallic lead into white lead paste takes only 48 hours in place of from 3 to 4 months by the old Dutch process, and the covering power is claimed to be 50 per cent. greater.

And now, gentlemen, I venture to crave your indulgence, while I direct your attention to one or two matters of a technical nature. In seeking to find a subject for some brief observations in this direction, I have felt that I could not do better than follow the unwritten law on such occasions and confine myself almost entirely to that branch of our common profession with which I am most familiarly acquainted. The business of gas engineering is one in which, as in most similar directions, great developments have been made in recent years.

Looking back over our records, I was somewhat astonished to find that although the proportion of our members specially interested in gas engineering matters is at present about 10 per cent., and was, I believe, even greater in the past, yet during 46 years we have only had 17 papers bearing on such subjects. The following list will show that while in these papers many important points were discussed, there are still other interesting topics which have never been brought forward.

The first paper was on "Gas-meters and pressure-gauges," by Mr. J. Willcock in 1860; followed by "The Manufacture of Coal Gas," by Mr. A. F. Wilson in 1864; "Modern Gas-works at Home and Abroad," by Mr. H. Gow, 1868; "The Prevention of Leakage in Gas and Water-mains," by Mr. C. M. Barker, 1869; "The Methods employed in the Determination of the Commercial Value and Purity of Coal Gas," by Mr. F. W. Hartley, 1869; "Apparatus employed for Illumination with

Coal Gas," by Mr. W. Sugg, 1869. Three papers on charging and drawing machinery for coal gas by Mr. J. Somerville, 1873, Mr. F. W. Hartley, 1875, and by myself in 1891. Two papers on gas-engines by Mr. C. Gandon in 1881, and by Mr. S. Griffin in 1889. "Illumination by means of Compressed Gas," by Mr. Perry F. Nursey, 1881; "Modern Improvements in the Manufacture of Coal Gas," by Mr. R. P. Spice, 1886; "Gas Substitutes," by Professor V. B. Lewes, 1893; "Gasholder Construction," by Mr. E. L. Pease, 1894; "Automatic Gas Station Governors," by myself in 1897; and "Gas-works Machinery," by Mr. E. A. Harman in 1898.

Several gentlemen intimately connected with the gas interest have occupied the chair of the Society, but the unwritten law already mentioned, not having by that time come into use, Mr. C. Gandon did not confine himself to the review of his own side of the profession, but noted the general achievements of engineering during the year preceding his election. Mr. W. A. M. Valon confined his remarks to another branch of his work, viz.: water and sanitary engineering. Another gas engineer, Mr. C. C. Carpenter, who would in the ordinary course have been our president some few years back, found his increasing duties so onerous that he could not afford the time necessary for the presidential work of the Society. Under these circumstances I feel that a review of the improvements in the methods of manufacture, and in the various engineering work carried out in this branch of our profession will not be out of place. That a vast amount of work has been done in this way is beyond question. The greatly increasing size of the gas-works necessary to supply our cities with gas has demanded considerable engineering ability on the part of those engaged in their erection and superintendence, a demand which has resulted in the growth of a distinctly new class of engineers with specialist qualifications in this branch of the profession.

The staple raw material in gas making is coal, and one naturally begins with the reception and housing of that article. The mechanical unloading of coals from ships and barges has recently engaged the attention of many engineers, and one of the systems which has now been largely adopted is the use of Hone's patent grabs which work with a single chain. These are lowered into the hold on to the coals and then on the hauling in of the chain to which they are hung, the grabs gradually close, filling themselves with coal as they do so. The rate at which these automatic grabs can unload a ship when used with hydraulic derricking cranes has been proved at Beckton to be a little over 50 tons per hour. This speaks exceedingly well for the arrangement, as it shows that while with the grabs the

number of men required is considerably less, the speed is maintained.

About 100 of these grabs are now in use at various gas-works in London alone. At several of the works of the Gas Light and Coke Company there are pillars of brick and ironwork, round which the coal is deposited from the trucks as received and afterwards lifted by the hydraulic cranes on the tops of the pillars, by means of these grabs and placed in the smaller trucks running into the retort-houses, as the coal may be required. Mr. George Livesey was undoubtedly the first to adopt continuous conveyors on a scale of any magnitude, at the Old Kent Road Works, where he installed plant capable of dealing with the coke from eight ranges of through retorts to the coke breaker, yard or store, and since then (1890) many others have adopted the system, both for carrying away the coke and for bringing the coal to the stores or retort-houses. Where sufficient coal is required perhaps the simplest and most efficient plan is to provide overhead railways into the coal stores and retort-houses with self-emptying trucks drawn by locomotives. Where smaller quantities, however, have to be dealt with, the continuous conveyor has many advantages.

After the storing of the coals we come naturally to the heating of the retorts. The principles of regenerative firing are becoming every year better understood, and the very elaborate arrangements which Siemens, Klonné, and others introduced some years back are giving place to more simple methods, which appear to give equal if not greater satisfaction. The intricate channels for the heating of the air supplies have been found unnecessary, and simple settings built with ordinary tiles and firebricks are now being used in most of the larger works, though in moderate sized works some of the patented systems, notably Mr. Hislop's, have been largely adopted, and with considerable advantage. With the exercise of a little care, a large saving will be effected in the fuel necessary for carbonisation, but to get the best results those in charge should be thoroughly acquainted with the underlying principles of the process. A knowledge also of the methods of testing the gases in the furnace or producer, the combustion chamber and the flues, will enable the engineer to accurately adjust the quantities of air both for the primary and secondary supplies.

The system of sloping retorts was reintroduced in 1889 by M. Coze, of Rheims, and these have been very considerably adopted in this country. M. Coze, although not the original inventor of sloping retorts, was the first to make their use practical, and he deserves every credit for his labours. The varying nature, however, of the coals to be dealt with in British gas-

works has prevented the more general adoption of retort benches on this system. The differences in the angle of repose of the various classes of coal is the great trouble, causing as it does much difficulty in getting an even layer and in effecting the easy removal of the coke, especially when the retorts are cracked and uneven. However, there are a large number of works where the charging and drawing of such retorts goes on daily with much success, and a large new works in the North is to be fitted with them. One suggestion, which I feel never received a sufficient trial, was that proposed by Mr. G. C. Trewby, by which a plate was inserted over the coals while they were being put into the retorts and prevented their sliding down when the retort was set at as high an angle as 35°; this high angle rendering the removal of the coke an easy matter.

Stoking machinery has been increasingly employed during recent years in order to do away with much of the more arduous labour in the retort-house, and at present there are two firms which stand pre-eminent for their apparatus—Messrs. Arrol, who manufacture the Arrol-Foulis hydraulic machinery, and Messrs. West & Co., who make Mr. West's machines, which can be driven either by rope gearing, compressed air, or manual labour. Both these systems give admirable results and considerably reduce the amount of labour required in the filling and emptying of the retorts. In each case the designer of the plant is a gas engineer of considerable experience, who has brought that experience to bear in producing a machine which requires very particular care in its arrangement, as it is subjected to the cutting influence of the coal and coke dust, which has such a very deteriorating effect on all machinery.

For many years past considerable expense has been incurred in providing baths, &c., with hot and cold water supplies, for the use of the stokers, but it has been found that they are not used to that extent it was hoped might have been the case, and they speedily get dirty and uncared for. A recent application of a simple shower or shower-and-spray fitting for this purpose seems likely to meet a better fate, as there is a constantly descending stream of clean water, which, as it fulfils its purpose, goes at once to the drains instead of forming an accumulation of dirty water around the bather.

Coke, the by-product of the retort, is now largely used for heating, both for commercial and domestic purposes. The public are beginning to find out what scientific men have known for a long time, that its heating power is very nearly as great as that of coal, being, when properly used, in the proportion of about 13,500 to 14,700, these figures representing the number of heat units evolved by a pound of each substance.

Coke breeze, which at one time was almost a drug in the market, is now used in so many ways that its price is well upheld. With forced draught it can be easily employed for steam raising, and mixed with sand and cement, forms admirable concrete. The mechanical breaking of coke has largely developed its use for domestic purposes, the loss of weight in the coke being not more than 5 per cent. with the best breakers, and as I have already said, the residue, breeze, finds a ready sale.

Although not strictly bearing upon engineering the question of the recovery of the cyanogen, which is always made in a gas-works, could hardly be left out of a list of the improvements made in the methods of manufacture of gas. The cyanogen, which is a gaseous compound of nitrogen and carbon, is produced at the later periods of the carbonisation of the charge of coal, and is now principally valuable for export purposes in connection with the recovery of gold from its ores, when it is employed as cyanide of potassium. The amount recoverable from one ton of coal varies from 5000 grains at low heats to 10,000 grains at high heats.

The methods generally adopted for its removal from the gas are :—

1. By treatment of the gas as it leaves the scrubbers when all the ammonia has been removed, the gas is then passed through soda or potash in solution in the presence of an excess of iron salt, when from 4 to 4½ lb. of crystallised ferrocyanide of soda or potash is recoverable from one ton of coal carbonised. The great thing to be noted for the complete recovery is that a prolonged and intimate contact between the gas and the alkaline iron solution is necessary. At one time the formation of sulpho-cyanide was considered undesirable, but means have now been devised for rendering this equally useful.

2. By the treatment of the gas liquor with iron salts when the cyanogen is precipitated as Prussian blue.

3. By the use of oxide of iron in the first purifier for its removal. This plan has been considerably adopted on the Continent, but has the disadvantage of not recovering so much cyanogen as by the washing process, the latter exceeding the former by nearly 50 per cent. Where the recovery takes place in the purifiers all ammonia must first be removed and a long contact secured with the oxide in a moist state and at a low temperature. A further trouble is that the continuous revivification of the oxide reduces the quantity of cyanogen that it will remove.

Weldon mud is the name of a by-product from the manufacture of bleaching powder, and consists principally of hydrated

oxides of manganese (MnO_2 and MnO) and of calcium. The advantages of this material for the removal of H_2S are very considerable. Instead of charging the purifiers frequently, as is the case with oxide of iron, a small quantity of air is admitted into the vessels, which oxidises the material and renders charging much less frequent. The Weldon mud is used until it contains from 50 to 60 per cent. of free sulphur, and might even be used still further, but this extent is generally considered to be the highest that is profitable. The crux of the question, as between Weldon mud and oxide of iron, is purely a matter of the price at which the two materials can be obtained.

While upon the question of the use of by-products of other manufactures for the purification of gas, a precipitated oxide of iron may be mentioned which has been introduced of late years. It contains 95 per cent. of pure hydrated oxide of iron, and can either be used to assist spent oxide, or mixed with sawdust, coke, or any other inert and porous material. As sent out it is in a very fine powder, and can be worked up in the usual way to from 60 per cent. to 70 per cent. of sulphur. When such material has to be sent abroad, the saving in freight, as compared with bog ore, must be considerable.

The use of oxygen for the revivification of the oxide or Weldon mud in the purifiers was, perhaps, rendered commercially possible by the introduction of the Brin process of extracting the oxygen from the air. Our esteemed past President, Mr. W. A. M. Valon, was early in the field, and to him is largely due the rendering useful of this plan. He it was who carried out the earliest experiments at the Ramsgate works, and there he proved its utility. He has recently informed me that he is still using this process, and is still as much in favour of it as ever. There is no doubt that the use of pure oxygen has many advantages over the employment of atmospheric air, containing as the latter does such a large proportion of nitrogen, which is only a diluent, and serves no useful purpose when mixed with the gas.

One of the greatest helps to a scientific knowledge of the strains, &c., governing the design of gasholders, was the publication in the 'Gas Journal,' and afterwards in book form, by Mr. F. Southwell Cripps, of his notes on 'The Guide Framing of Gasholders.' This book has done more for the engineering of these structures than perhaps anything else, and has led many to take an intelligent interest in the principles of gasholder construction who would otherwise have been content to plod on in the old rule of thumb style which generally prevailed before this book appeared.

The gigantic gasholders on the cantilever system which Mr.

George Livesey was, perhaps, the first to undertake, have necessitated a much more thorough knowledge of the stresses involved, and to him and Mr. Cripps no little thanks are due from the gas engineering profession for their aids to this knowledge. The articles by the latter gentleman were originally intended as a criticism on the suggestion for the abolition of guide framing first suggested by Mr. Webber. It is probably this fact which has prevented many from following as closely as they might the admirable chapters on the designing of the more ordinary types of gasholders with cast-iron columns and wrought-iron or steel standards. If Mr. Cripps could be induced to publish a small pamphlet giving merely the details of his investigations into these more every-day strains, I feel sure he would not only earn the gratitude of his professional brethren, but would reap the reward in other and perhaps more solid ways. In the year 1889, which seems to have been very fruitful of new ideas and processes, columnless gasholders were first suggested in a practical form, either with spiral guides, or with wire ropes to keep the floating bell horizontal. Both these systems have been adopted in a considerable number of works, and appear to have given every satisfaction. They have certainly shown that the heavy and costly guide framing, which was in past years considered necessary, can be largely done away with, and that without endangering the safety of the structure. Although personally interested in the rope system of guiding, having taken out a patent for this method some three months only after Mr. Pease, I am fain to confess that for large holders I do not care to advocate the abolition of all guide framing, but much prefer Mr. Livesey's plan of retaining the framing to a certain height, leaving only the upper portion free or guided by wire ropes. That this is quite feasible has been proved by Mr. Livesey's gigantic example at East Greenwich.

Gasholder tanks have of course, like the gasholders, assumed much larger dimensions, and in connection with their size, considerable changes have been made in the material of which they are made. The old-time brick tank with puddled backing has now largely given place to the concrete tank, either with puddled backing, or, what is more common, the face rendered with nearly neat cement. The saving in cost is very considerable, and the tightness and durability are not in any way impaired. One of our past presidents, Mr. C. Gandon, in making a concrete tank somewhat recently, conceived the idea of casting blocks of concrete from time to time. Whenever he removed any old retort work, and had sufficient broken firebrick, &c., he cast blocks of the right shape to form part of the wall of a proposed tank, so that when the tank was started, a

number of these blocks were ready to be merely jointed together in position. This plan has many advantages, as it saves ground space which would otherwise have to be provided for the storage of the broken bricks, and it certainly helps largely to keep the works tidy. It however necessitates the providing of plans of the extensions long before these are absolutely required. I am wondering, however, in how many works this has been done, and a clear and distinct plan of extensions provided, to which the works may be converted as the output increases : I fear in but few except the larger works. Effort in this direction should form an interesting and instructive work for any gas manager, and might well become a source of no little profitable discussion whenever several congregated together.

To return however to the use of concrete in gasholder tank construction, I can recommend to anyone about to undertake such work the plan adopted by myself in the construction of an 80-foot tank somewhat recently. The concrete was mixed dry on the ground level with only one turning, and then shovelled into the hopper of a shoot leading to the stage at the level where the concrete was to be used. It was then watered and turned over and was found to be most thoroughly mixed; in fact, I have never seen better mixed concrete than in this instance. The method occasionally adopted of wetting the concrete before it is put into the shoot is one which I cannot recommend, as it has a tendency to coat the sides of the shoot with cement, and leaves the ballast or other aggregate to pass down without the proper amount of cement.

It is unfortunate that little new data or little information of a scientific nature have been forthcoming as to the strength of tank walls, as the old methods of calculation are distinctly unsatisfactory, and until some one with time and inclination to experiment takes the matter in hand, mere rule of thumb must continue to largely prevail in these matters.

The recent expiry of the Otto patent for the 4-cycle gas engine, which was first introduced in 1876, has led to a number of makers of such plant including these engines in their manufactures, and there is little doubt that the use of gas engines will increase in consequence. But gas engineers do not sufficiently push their use, nor do they use them sufficiently in their works. In my opinion all motive power in a gas-works, except that for the exhausters, which is so very variable in its load, should be furnished by gas engines. Scrubbers, pumps, coke-breakers, elevators, stoking machinery, could all be driven by this means, but how often is it so done? Let the public see that we practice what we preach, and they will the more easily believe us.

Mr. Denny Lane's suggestion was a distinctly good one, viz. to supply electricity for electric light by means of gas engines, but this has not been sufficiently encouraged, nor have gas engineers taken this matter in hand, or they could have kept much of the electric lighting within their own power, and with little if any decrease in their gas consumption.

Gas engines are now made on the Continent up to 1000 horse-power, and even 1500 horse-power, if desired, and to be used with coal gas, Dowson gas or high furnace gases; the use of these latter effecting a considerable saving in fuel as compared with their use for heating boilers for steam engines.

While upon the subject of internal combustion engines, I might mention a coal-dust burning internal combustion engine, of a very novel description, which has been invented by Mr. P. F. Maccallum of Helensburgh, Dumbartonshire, and experimentally tried on a small scale at Edinburgh. The construction of the engine is such that no lubrication of the combustion cylinder is necessary, while at the same time the rubbing surfaces of the piston and working cylinder are thoroughly protected from heat and dirt by an ingenious method of interior water circulation. In working the experimental engine a volume of air is compressed by the up stroke of the piston into the upper part of the combustion cylinder. The proper quantity of coal dust is then injected by a jet of high pressure air on to a wrought-iron plate attached by a stud to the piston, and maintained at a high temperature by the successive combustions. Immediately the first portion of the coal dust strikes the plate, ignition takes place, and a working down stroke is made, When the piston reaches the bottom of its stroke the exhaust valve opens, allowing the combustion products and suspended ash to escape. A fresh charge of air then ascends through automatic valves from the crank chamber and is compressed into the upper part of the cylinder in readiness for another combustion stroke, and so on. As the fuel never comes into contact with any but dry surfaces, and is always kept in a state of suspension and motion, no accumulation of ash or dirt takes place within the engine, the force of the exhaust being amply sufficient to sweep out any solid matter which can possibly enter the engine through the fuel feeder. The engine is equally satisfactory when employed with oil.

The engine working with coal dust gives diagrams of good and regular form showing about 15 horse-power at a speed of 150 revolutions per minute, with a fuel consumption of about $1\frac{1}{2}$ lb. of coal dust per horse-power per hour. The consumption of fuel would be much less but for several defects in the design of the experimental motor. In fact, from one cause and another,

nearly one half of the fuel injected at each stroke is exhausted without having done any useful work. Notwithstanding the defects alluded to, inseparable perhaps from a first motor presenting so many points of absolute departure from previous practice, the engine has been pronounced a practical success by many well-known experts who have examined it in operation. Professor Stanfield predicts that a larger engine of improved design will give a horse-power for a consumption of about ½ lb. of coal per hour. Almost any kind of coal can be used, and the cost of pulverising is stated to be from 6*d.* to 9*d.* per ton. The inventor is now engaged in forming a company to fully demonstrate his system by building a larger engine on improved lines.

The troubles with the labourers engaged in gas works in 1889, first at Beckton, then at Manchester, and finally at the South Metropolitan Gas Company's works will be in the memory of most of us, more especially on account of the success of the latter company, who were afterwards able to announce that they would receive no union workmen. The strike cost them a considerable sum of money, and was perhaps the direct cause of their profit sharing scheme, which provides a bonus of one per cent. on the year's wages of any workman for every 1*d.* reduction below 2*s.* 8*d.* per 1000 cubic feet. This was a successful attempt to identify the workman with the interests of the company. At Beckton, however, the directors of the gas company erected, and have kept in order since that time, complete barracks, with officers' quarters, bakeries, &c., in accordance with an arrangement with the War Office that in the event of the stokers leaving, soldiers from the Royal Artillery shall be quartered in the barracks on the gas-works, and accompanied by their own officers. Beds, blankets, &c., are kept dried and aired continually.

Probably the strikes were the cause of one of the most conspicuous instances of evolution in the manufacture of gas—namely, the introduction into this country of the system of carburetted water gas, which had been considerably used in the United States. Originally patented in 1824 by Mr. J. H. Ibbetson, it never proved a commercial success until, in 1873, Professor T. S. C. Lowe introduced what is now termed "The Lowe Apparatus," which is really the foundation of all the carburetted water gas plants in use in this country. All these plants make use of the well-known fact that superheated steam passed through incandescent fuel becomes separated into its component parts, hydrogen and oxygen, the latter combining with the carbon of the fuel to form carbon monoxide, and the former passing off by itself. These gases are then enriched by being

mixed with oils vaporised by heat, and are then further fixed, or rendered permanent, by prolonged contact with heated surfaces.

The fact that the name "Carburetted water gas" contains the term "water gas" is unfortunate, as many would-be clever people who have that "little knowledge," which is "a dangerous thing," have been raising considerable agitation in many towns in which this plant is being placed. The one fact which they have failed to grasp is, that while water gas, *per se*, has no smell, carburetted water gas has, if possible, a stronger and more penetrating smell than coal gas, and yet, day after day, we see the statement advanced in the press, that the danger of the adoption of this system of gas-supply is the fact of its possessing no smell, while it is of a much more toxic character than the ordinary coal gas. The pronouncements of scientific men seem to have no effect on these statements, and one finds them repeated time and again.

That carburetted water gas does contain more carbon monoxide than coal gas is not to be denied, but that the extra quantity which will be delivered through the mains to the consumers will cause any greater number of accidents through escapes, I do not think at all likely. As one eminent scientific gentleman remarked, "gas is not made for breathing." At the present time, plant, to the extent of 97,795,000 cubic feet per day has been erected by Messrs. Humphreys and Glasgow, by the Economical Gas Apparatus Construction Company, and by Messrs. Samuel Cutler & Sons, in different gas-works in this country. That such a number of those responsible for our gas supply should have favoured this system clearly indicates that there must be in it several points of advantage to the gas maker. First and foremost the small area required is, in some works, the most important consideration, and nearly four times the quantity can be made of carburetted water gas as could be made of coal gas in the same area. The initial cost is comparatively low, while the number of men employed is much less, but what perhaps interests the gas engineer more is that it uses up his stocks of coke, and enables him to ask for and obtain a much higher price for what he has to spare. Then, again, the rapidity with which a set can be put into complete action is, in our foggy and changeable climate, a great advantage. A completely cold setting can in four hours' time be in full work as against some forty-eight hours with coal-gas retorts. The simplicity also of the regulation of the candle-power of the gas by the control of the quantity of oil used in carburetting is distinctly in favour of this process, while the fact that troubles with naphthalene in the district are much reduced, if not entirely removed, forms yet another reason for its popularity.

The contractors for this plant are generally prepared to guarantee that the plant shall produce 1000 cubic feet of 22-candle gas, with not more than 50 lb. of coke nor more than 4 gallons of oil, and this under very stringent conditions. That the contractors have almost invariably improved considerably upon their guarantee is a clear proof of the satisfactory nature of the various designs for the apparatus. An average of some twenty-four tests in the same number of works gives a candle-power of 22·56 with a quantity of oil of 2·99 gallons per 1000 cubic feet.

The Peebles process of making permanent high quality gas for enriching ordinary coal gas has been considerably adopted throughout the country. Using, as it does, almost any class of oil, it has, with the water gas plants, distinctly governed the price of cannel coal, and prevented that commodity rising to the high figure it seemed destined to reach.

The plant is very simple, and consists mainly of a retort set at a slight angle and heated to from 900° to 950° C., or about black red. The oil is run into the retort and gasified, passing away to condensers filled with the oil making its way to the retort. This washing with oil removes all the non-permanent gas, so that only the gas which will remain as such, passes away to the mains, while that which has been condensed out by the oil is returned to the retort with the fresh oil, and is there either gasified into permanent gas or else left in the retort in the form of a dense coke, consisting of nearly 96 per cent. pure carbon. It has been found with the gas made by this plant, as well as with that made in the carburetted water gas plants, that the enriching value of the gas is considerably greater than its direct illuminating value would lead one to believe, and this to an extent of from nearly 25 to 30 per cent.

The Clark-Maxim carburetters, and also that of Mr. Cripps, are now largely used in gas-works for enriching the gas as it leaves the works, and in them a highly volatile liquid carburine is generally used, although naphtha or benzine are also frequently employed. These systems are said to reduce the number of naphthalene troubles.

A few years back the discovery of the possibility of manufacturing acetylene gas—which Professor Vivian B. Lewes had been endeavouring to show was the principal cause of the illuminating power of coal-gas—from carbide of calcium, led to innumerable patents and reports that a further rival to coal gas had arisen which would entirely supersede it in a very short while. This, however, it has not done, although it has been considerably introduced for the lighting of private houses in country districts which the ordinary towns' gas mains do not reach.

The necessarily high price of carbide of calcium, which requires a fairly strong electric current for its manufacture, has done much to restrict the use of this acetylene gas, while numerous accidents with it, both at home and on the Continent, have made people chary of adopting it. One of the unfortunate circumstances connected with this gas is that it does not hold its high illuminating effect when used as an enricher of lower candle-power gases. When it is employed in this way its enriching value is considerably reduced far beyond what would generally be the case with other rich gases. It is therefore very different in this respect from either carburetted water gas or the gas made by the Peebles process of direct oil gas enrichment. The great simplicity of the making of acetylene gas from calcium carbide will no doubt assist in its adoption, but that many have been grievously disappointed over it can be easily seen by an examination of the Patent Office records.

For some years past I have devoted a large amount of time to photometrical matters, more especially with the aim of devising a photometer which shall require no calculations of any sort, so that it may be placed in the hands of any one of ordinary visual activity, but who may not have that acquaintance with decimal arithmetic which is necessary with present methods. A few years ago I read a paper on the subject before the North British Association of Gas Managers dealing with the progress I had then made in this direction. I have since then had the matter simplified through the introduction by the Metropolitan Gas Referees of their new form of photoped testing apparatus. They have gone largely on the same lines as I was working on, in that they bring the beams of light from the two sources—namely, the standard and the light to be tested—upon one translucent screen. The principle of measuring the time which it takes to consume the one-sixth part of a cubic foot of gas when the two beams of light are equal, has enabled me to arrange for the complete elimination of all calculations. I attach the clock to the meter, and have a connecting rod by which the clock may be started and stopped, when desired, by the meter, and upon the face of the clock I have a second circle divided into candle-powers and tenths about the ordinary circle showing the seconds. In making a test with this instrument, the procedure is exactly similar to the Gas Referees' new instructions, in so far as regards the comparing of the beams of light and the settling of the proper rate of travel of the meter, but the latter, having the attachment for correcting for the variations of temperature and barometrical pressure, removes the necessity of calculations for this correction. As soon as the rate of travel is found, the clock is started by depressing the lever in the ordinary way; this not only starts

the clock, but puts into gear a wheel which will have the effect of stopping the clock when the meter has made two revolutions. The position of the hand indicates on the outer circle of the clock the exact candle-power of the light being tested. This system could also be applied to the ordinary bar-photometer. Any engineer can readily set out such a circle for his clock after an examination of the table provided by the Gas Referees.

With regard to the more chemical part of gas testing, the principles remain much the same—namely the absorption by different reagents of the several constituent gases, and noting the diminution of the volume of gas after absorption. The Cooper tube or eudiometer has been almost entirely superseded, on account of the great trouble involved in getting perfectly accurate results, and a host of other apparatus have come into use, principally the Bunte Burette, the Frankland and Ward, and the Orsat-Muencke apparatus. In the latter arrangement separate chambers are provided for the absorption by each of the reagents, and the gas is forced into each in turn, the diminution in each case being noted. This is very useful and convenient for the partial analysis of gases, more especially furnace, producer, and flue gases, while the Frankland and Ward apparatus, which is somewhat elaborate, is more suitable for thorough analysis, but is only to be found in very complete gas-works laboratories.

Having only recently dealt with the subject of governors in my paper before the Society, I need not enter into great detail regarding the improvements in them. At present it would hardly be possible to find a governor made without compensation of some kind for the variation in inlet pressures. The principle of working a governor at some distance from the works by means of an air tube and separate loading bell, first proposed by Mr. Foulis, has been adopted in a number of works, and the saving in main-laying thereby has been great. Several arrangements have been tried, with success, for the purpose of varying automatically the weighting of the bell according to the quantity of gas passing through the governor. The greatest trouble, however, which makers of these pieces of apparatus have to contend with is the desire on the part of most engineers for a governor of much larger capacity than is at all necessary. The area of the cone of the governor need never be greater than two-thirds of the area of the mains in connection with it, and where only a very small day consumption is found a smaller bye-pass governor may be fixed with advantage.

One of the greatest advances in gas matters has been the introduction of the Welsbach incandescent light. The early attempts were unsuccessful owing to the tender nature of the

mantles, and it was not until the use of collodion was introduced that it became possible to send the mantles from manufacturer to user. The patent for the use of the rare earths employed in the preparation of the mantles was perhaps more carefully drawn up than many others, as despite most costly litigation, the original patent has been upheld throughout. The first patent has now expired, but there is still another patent in the hands of the Welsbach Co. which has some years to run, and which contains protection for a very essential element in the making of the mantle. Into the details of the manufacture I need not enter, but a remark may well be made on the enormous increase of light obtainable by the incandescent system over the ordinary flat flame or any other form of burner, giving as much as from 25 to 30 candles per cubic foot of gas as compared with some 3 to 4 candles per foot with argands or flat flame burners; or in other words a Welsbach burner will give a light of 20 candle power for 1000 hours for 2*s.* 3*d.*, while a flat flame burner for a light of only 16 candle power for 1000 hours will cost 15*s.*

That this burner has done more for the extension and retention of gas lighting than any other invention of the last twenty years cannot be denied, as not only is the light much cheaper but a reduced quantity of gas required means a smaller quantity of oxygen consumed and air vitiated, an important point in small rooms. There is, no doubt, still further improvement necessary, and that is in the direction of strengthening the mantle. Wherever vibration exists the mantles speedily go to pieces, and hence, despite elaborate mechanism to preserve the mantles, they are still absent from many of our street lamps, where they would be most admirably placed. This is owing to the large number of mantles completely spoilt in a very short time, and when a stronger mantle can be supplied there is little doubt that our streets will speedily be better lighted.

The knowledge of the ordinary gas-fitter of the elementary principles which govern the distribution of gas is very limited; he seldom knows anything of the difference in pressure due to the varying levels, the difference in quality of the gases in different towns, or the difference in the respective quantities that can be passed through a pipe of a given size and of a certain length according to the variations in the specific gravity of the gas. When called upon to lay pipes and light rooms, he goes by any old rule-of-thumb method which his father or grandfather practised. How many could set out a diagram showing, say the amount of light thrown upon the floor by the lights they suggest for a certain room? how many know even the most ordinary details of gas manufacture? Surely here is a field for those who have the necessary knowledge to begin by

enlightening the gas-fitter, and so save trouble later on. Every gas manager in the three kingdoms should give lectures periodically to those in his town interested upon these points, and if he cannot himself do it, some one who has perhaps the time or requisite knowledge should be engaged to give such lectures in as popular a manner as possible. The addition of a small model gas-works, or even the simple old experiment of the clay pipe, will help many to better understand the method of the manufacture. For my own part, I have always found these lectures listened to with interest by all classes of the community.

And now, gentlemen, I think I have said enough to show that a gas engineer at the present day has to be educated in most of the branches of the profession of a civil and mechanical engineer, and to aid him in this direction much good has been done by courses of lectures in most of the large centres. The admirable reports of the various meetings and the careful selection of interesting matter in our technical journals, the "Gas Journal" and the "Gas World," have also helped considerably, but in addition to these means the gas engineer must apply himself to the acquirement of knowledge from every possible source. He should make it a rule to note down every item coming to his notice which may at any future time be likely to be of use to him. He must study every detail of the apparatus under his control. He should be able to take to pieces and remake any portion of the works, however unimportant; it is not sufficient merely to know their use and purpose. He should be able at any point in the process of gasmaking to make a test both of the gas itself, and of the material used in its purification. He should study not only the stresses in the various structures but should also note the effect of wind, weather, and oxidation upon them. If he be sufficiently inventive he can make for himself, very cheaply, almost all the testing apparatus he may require, provided he understands correctly the principles upon which the tests are made. The examinations annually held by the City and Guilds of London all over the country, are most admirably conducted and of a thoroughly practical character. A glance over the questions of the past few years will satisfy any one that they are not set by mere theorists, but by men with a thoroughly practical every-day experience of the needs of a gas engineer. I would strongly advise all young men connected in any way with gas-works to study and to strive to pass these examinations as they will find that to hold the certificate of the City and Guilds is to have a guarantee of their practical acquaintance with the working of a gas-works plant. General knowledge of all branches of engineering may be obtained in few better ways than by attendance at such meet-

ings as ours. For my own part I cannot recollect the occasion when I have been present at the reading of a paper, and the subsequent discussion, when I have not gone away with some information likely to be of benefit to me, and I hope to see a full attendance each evening during my year of office.

But, gentlemen, I should be sorry to weary you by unduly prolonging these disjointed, and I fear not too interesting remarks. I thank you very much for the patience with which you have heard me, and I thank you also, once more, for your goodness in conferring upon me the high honour of acting as President of the Society to which we are all so proud to belong.

March 5th, 1900.

HENRY O'CONNOR, President, in the Chair.

THE CLOSING OF BREACHES IN SEA AND RIVER EMBANKMENTS.*

By Richard F. Grantham.

It may perhaps be remembered that on November 29, 1897, a month after the author had the privilege of reading his paper on "Sea Defences" before this Society, an extraordinary tide occurred in the estuaries of the Thames, and of other rivers draining Essex and Kent. This caused an immense amount of damage to the sea and river walls protecting the low-lying lands of Essex and Kent; towns, villages, and thousands of acres of land being flooded, lives being lost, cattle drowned, and much damage done. The author has had the opportunity of professionally examining a large number of the sea and river walls affected by that disastrous inundation, and of stopping some of the most serious breaches. Accordingly, it seemed to him that it might be useful to describe the secondary causes of the mischief done, and the works undertaken for undoing it.

The great rise of tide was due to violent and suddenly changing winds. A very heavy gale from the south-west had been blowing on the day previous to the overflow, heaping up the waters in the Channel when the spring tide had attained its highest level. Then the wind suddenly changed to north-west, raising the level of the tide from the North Sea. The effect of this was, particularly in the rivers and creeks, before one tide had receded, to blow up another, as it were, upon the top of it. The actual rise of the tide was 15·16 feet above Ordnance Datum on the gauge at Sheerness, which may be considered a central point for that district. This is 2 inches higher than the author's record of the great tide of January 18, 1881, when 1500 acres of land in Canvey Island were flooded.

In November 1897, two things contributed to the disasters. In the first place, a very large proportion of the walls was lower than the level of the tide, and in the second, owing to the dry-

* The Bessemer Premium was awarded to the Author for this paper.

ness of the summer and autumn, the tops of the walls, which are formed of earth, had become very much cracked. There had been little or no rain, as usual, in the autumn to swell the clay and close up the cracks, and into these cracks the tidal water poured. The consequence was obvious; it thrust out the back slope, and the front slope, being unable to withstand the pressure, also gave way. The greater number of the breaches were easily stopped, and no doubt all could have been, if taken in time, but for considerable difficulty in getting labour; and had not, in some cases, considerations of cost on the part of the landowners delayed the immediate prosecution of the work. In course of time the more serious breaches became so enlarged as to be beyond the ordinary means of stopping. It was in these circumstances that the author assisted in closing three of the most serious gaps.

Dagenham Breach.

The history of the closing of the Dagenham breach by Captain Perry is sufficiently well known, but perhaps a recapitulation of its chief features will not be out of place.

He relates that it was occasioned by the blowing up of a small sluice or trunk, damage which could easily have been repaired had the work been undertaken at once. This, however, was not done, and at the end of seven years a channel had been cut by the tide 400 or 500 feet wide, and 20 to 40 feet deep; various attempts to close it with piles, sunken barges, by throwing in baskets filled with earth and ballast, and by depositing chalk, had all proved futile. The range of the tide was 22 feet. It was estimated that from beginning to end 120 acres of marshland were washed out and carried into the river. The surface of this area was comprised of "clayie" ground, probably alluvial deposit, overlying "moorlog" or peat, under which was 1 foot or 18 inches of blue clay, and then gravel and a sort of quicksand.

On the failure of all attempts to keep the tide out, the landowners were in despair, when one Boswell submitted a scheme, and undertook to close the breach for 16,000*l.* He proposed to sink six large chests, 60 feet long, 30 feet wide and 20 feet deep, with a space between them of 12 feet, the spaces to be filled up with piles and drift-work. In the upper part of each chest was to be a draw door, to stand open until the spaces were filled up. But at the commencement of the work the scour increased so that the foundation of the chests could not be made level. Only one chest was made, and this was very quickly

washed out. Then piling, and sinking a barge was resorted to, but only to end in failure.

Captain Perry then propounded a plan, and undertook to close the breach for 25,000*l.* The principles he laid down for the execution of the work were—

"That a sufficient sluice should be fixed at least down to the depth of low-water mark, or some feet below it, so as to ease the force and fall of the current.

"That where there is a rise of tide of 22 feet, greater care ought to be taken to make the foundation of the dam tight and secure, and prevent leakage underneath."

He proposed that the body of the dam should be entirely composed of good earth or "clayie" sort of ground without any timber work, except a row of dovetailed piles driven through the middle of the dam, and a strong drift-work to be made as a buttress or foot wharf on each side to uphold the banks. He accordingly drove the dovetailed sheet piles, taking care that their heads did not project more than one or two feet above the ordinary level of low water. He also inserted a sluice 40 feet wide with draw doors, and took the precaution of constantly shutting them down to pen the water when it had ebbed to the level of the height of the dam as it was raised. The height of the dam, reckoned from the bottom of the breach, was 35 feet; the breadth at the bottom was 150 feet, while at the height at which the foundation was made above low-water mark, the breadth was 104 feet, and at the height at which neap tides were shut out it was 36 feet broad.

In this way, in the summer of the year 1717, the neap tides were shut out, but in September of that year the tide overflowed and washed out the dam. A second sluice was then erected and after much trouble, particularly with the men, neap tides were again shut out in June 1718. In the following September another overflow occurred, which broke down the dam and tore up 100 feet in length of the dovetailed piles. The work was repaired, and in June 1719 the tide was finally shut out and the dam raised and strengthened.

Middle Level Breach.

The method of closing the great breach in the Middle Level in 1862, whereby 6000 acres were inundated, was described, it will be remembered, by Mr. Baldwin Latham. Here the breach was closed by the driving of piles in pairs with a space between each pair for the admission of sliding panels 12 feet deep. After an unsuccessful attempt to lower the panels, they were again

let down and clay, sacks of gravel, and clunch were thrown in for a backing. By the employment of 800 men this backing proceeded as fast as the tide rose and the breach was successfully closed. Similarly at Portsmouth, in 1868, sliding panels were used in the dams made for enclosing the area for the extension of the dockyard.

Brading Harbour.

The first recorded attempt to reclaim Brading Harbour in the Isle of Wight was made by Sir Hugh Middleton in 1620, when an embankment was made along the line shown in Fig. 1, which successfully shut out the tide for a few years, but it was neglected and a high flood overflowed and destroyed it. There is no record of any further attempt until 1879, when the Brading Harbour Company undertook the work. In dredging the channel outside the embankment some of the old cills which formed part of Sir Hugh Middleton's sluices were found, the oak of which they consisted being as sound, and the arrises as sharp as when they were put down.

In the recent reclamation of the harbour great difficulty was encountered in closing the gap in the embankment (Fig. 1) which was laid out and formed by the late Mr. R. J. H. Saunders, engineer to the Brading Harbour Company, and many attempts were made before the work was successfully accomplished. The area reclaimed is about 600 acres, a smaller part of the harbour being left outside to meet the views of the Admiralty. The length of the embankment is nearly a mile, extending between St. Helens on the west side and Bembridge on the east side. As usual in such cases no difficulty was met with in making the embankment, until it became necessary to close the gap left at the Bembridge end. Three attempts were first made, but these although very nearly successful failed, with the result that a gap 70 feet long and 15 feet deep at low-water spring tides still remained.

At this time the author's firm was called in in consultation with Mr. Saunders, and a plan for closing was submitted to them. The plan consisted of constructing a dam (Figs. 2, 3 and 4) by driving two rows of whole timber piles 13 inches square, 12 feet between centres, 15 feet in the clay which formed the stratum below the hole, the distance back to front between the two rows of piles being 15 feet. In accordance with this plan the tops of the piles were driven to a level of 5 feet above low-water spring tides, and a double whole timber waling was bolted on to the

sea side of the front row of piles and a single balk to the inner side of the same row. A whole timber waling was also bolted to the land side of the back row of piles. The walings on the front row of piles were bolted together.

Each pile on the front row was tied to the corresponding land tie pile in the back row with a land tie of whole timber securely strapped and bolted, and the space between the inner and outer walings on the front row of piles was filled in with sheet piling driven into the clay; and a capping of whole timber strapped on to the tops of the piles in each row formed a staging from which the filling in of the dam might be carried on. Bags of sand were then thrown in behind the sheet piling, and chalk in front of it and also behind the bags, so as to form slopes of about 2 to 1 on each side of the dam.

While all this was being done, and in order to retain as much water as possible within the enclosure, a bank of chalk, 2 or 3 feet above low-water, was raised at a distance of 200 yards in rear of the dam; this bank prevented some of the scour of the water at the last of the ebb tide. Long whole timber piles were then driven on the inside of the inner front walings, having their tops 19 feet above low-water spring tide, strutted and tied to the back piles. Horizontal planking was spiked against these long piles, and sand deposited at the back of it as it proceeded. By this means, on June 26, 1879, the sea was effectually shut out. The base of the dam below the top of the sheet piling was strengthened and made good with clay, while above that level the embankment was made up with sand. All went well until October 18, 1879, when an unusually high tide overflowed the embankment, and after washing out the sand behind the planking, finally carried away the planking and the whole of the dam in the gap, leaving the gap rather deeper than before.

The next attempt was the erection of a cofferdam in the rear of the old line, and differing only in the width apart and lengths of the piles. Clay and chalk were thrown in behind the sheet piling. The scour, however, became so great that the main piles were loosened, and it was found necessary to draw some of the sheet piles. This, and also another attempt, failed. The dam was again restored, and a barge afterwards sunk, and at last the tide was finally shut out on February 23, 1880. The embankment was then made 35 feet wide at the top, and the road which connects St. Helens and Bembridge made over it.

Northey Island, Essex.

In the spring of 1898, the author was asked to undertake to close some breaches in the river walls of Northey Island (Fig. 5), in the river Blackwater below Maldon, Essex. Besides some minor breaches, there was one large one through which the tidal water, which then covered 200 acres of the island at every high tide, was discharged. The breach was 100 feet wide, and at the wall about 12 to 15 feet deep below high-water spring tide. In front of the breach there had been saltings, but the current, during the ebb and flow of the tide, cut a channel through these to the low-water channel of the Blackwater.

The water of high-water spring tides covered the land 5 feet deep, while at neap tides it did not rise more than 1 or 2 feet over the land, according to the varying conditions of wind and tide. The range of spring tides is about 14 feet. The area of the whole island was only 330 acres, so that in view of the state of agriculture in Essex at that time, the land was not worth recovering unless the breaches, and the large breach in particular, could be closed within a very reasonable limit of expense.

The work was not begun until July 1898, by which time the condition of the breach, and the drains leading to it, had become very serious. The surface of the island consisted of alluvial deposit, about 4 to 5 feet, overlying a bed of drift gravel, not dissimilar it its general character to the soil described in the case of the Dagenham breach, except that there area no peat. The main drains, which happened to lead towards being lech, had been widened to such an extent, by the fretting length of eir banks, that the largest of them, which the author St. Helens l over in the previous March, had actually become, As usual ianal 60 feet wide and 8 to 9 feet deep. It seemed the embankhe gravel underneath became charged with water, left at the Ileposit floated on it, so that the scour of the tide but these alt off the ragged sides of the drains—conditions that a gap 7Cnilar to those at Dagenham breach. Be this as tides still remaid widening of the drains considerably augmented

At this timf closing the large breach.

with Mr. Saundthe depth of the flood upon the land at 5 feet, as The plan consiwas, the quantity over the area of 200 acres driving two ronted to 43,560,000 cubic feet, and as the time between centreen the top of the flood and the clearing of the below the hole land of water was approximately three hours, the of piles being discharge was 242,000 cubic feet, or 6750 tons the piles were rtly discharged through two small sluices about tides, and a d re, and partly through the breach.

Under these circumstances, and bearing in mind the risks and consequent cost of driving piles straight across the breach, as at Brading Harbour and in other places, the author determined to form an inset or horseshoe wall (Fig. 6) round and inside the gap, so raising it by degrees as far as possible; and to put in a new sluice to discharge water accumulating behind the wall. There were four open drains to be crossed—two back ones at the inner foot of the old wall on each side of the breach, and two leading from the marsh direct to the breach.

At first it was intended to put light low dams of sheeting piles across these drains, and accordingly one was commenced in the back drain where the sluice was to be laid. The piles consisted of planks 11 inches by 4 inches, two rows being driven at the two ends of the sluice about 30 feet apart. The sluice was simply a wooden tube, 2 ft. 3 in. square, with a wooden tidal flap at the outer end. As soon, however, as the row of piles in the outer side was driven, considerable scour commenced on the outer flank of the row, and there appeared to be danger of its being swept away. Bags filled with clay and ballast were thrown into the hole by the outer flank, and the scour was effectually stopped. The back drain on the side of the gap, and one of the main drains leading to it, were filled up with bags of clay and ballast, and so easily stopped. In the meantime, the larger main drain was rapidly widening, and when the other drains were stopped, much of the water flowing off the island at every tide was diverted into it. An apron about 10 feet long, consisting of bags filled with ballast, was laid across the bottom of the drain, the bags being staked down with rough stakes, 5 to 6 feet long, driven through them. A sloping wall of bags filled with ballast and clay was then gradually built up; and these bags were also staked down. Clay was simultaneously thrown in at the back of this wall, and the top surface of both bags and clay was kept as nearly level as the great rush of water over it would allow. A rough kind of weir was thus formed, the sides of the drain on the down-stream side being protected with bags which were thrown in as fast as any appearance of scour showed itself. In this way the weir was brought up to the level of the land, earth being constantly added at the back to strengthen it.

While it was being formed, the base of the inset wall on both sides was being gradually raised. It was found that the rush of the tidal water, great as it was both in and out, did not cause any scouring of the surface of the marsh. The surface was approximately level, and although the grass was dead, the roots appeared to hold the earth together and the water flowed over the smooth surface without abrading it. In order to pre-

vent any new material put on from being washed away, the toe of the front slope of the new wall was built up of bags of clay 3 to 4 feet in height, the bags being staked down and the front of the bags protected by a row of stakes. The base of the wall was then widened with clay and carried up by degrees, every appearance of scouring being checked by the addition of bags and stakes. The inset wall round the breach was 265 yards long, and was raised 8 to 9 feet above the level of the marsh in about four months, and the tide was effectually shut out on September 9, 1898. The cost of forming the wall was 1100*l*. There was no difficulty in closing the remaining ten breaches, which were comparatively small. After they had all been closed the wall round the island was raised 18 inches to 2 feet so as to protect it from further overflow.

Grovehurst Breach, Iwade, Kent.

The same disastrous tide of November 1897 made a breach through the river walls of Cold Harbour Farm, Iwade, near Sittingbourne, Kent, and flooded rather more than 900 acres, part, about 630 acres, lying between the river Swale and the east side of the railway from Sittingbourne to Sheerness, and the remainder, about 280 acres, on the west side of the railway. The Ferry Road on the west side of the railway was also flooded about 2 feet deep. Before the author took the work in hand attempts had been made for about twelve months to close the breach, but although the work as far as it went was well done, it was not successful in stopping out the tide. The subsoil is alluvial deposit which is very soft and treacherous when covered with water. The pile dam was substantially put together and the piles were driven across the gap, but as it became narrowed to about 40 feet the scour became so great that in the soft soil the piles on the narrow part became loosened and gave way under the pressure of the rising tide. After some delay following the failure of these attempts the landowners affected met in March 1899, at the suggestion of the late Mr. George Webb of Sittingbourne, when the author was instructed to undertake the work of closing the breach.

In the meantime the Railway Company, fearing some damage to their embankment, stopped up a cattle arch and put tidal flaps to the drains under the embankment. This stopped the water flowing over the marshes and road on the west side of the railway, and thus limited the area of flooding and the quantity of water flowing through the breach. There is also

an old counter-wall separating the Ridham marshes from the Cold Harbour marshes, which prevented all except the highest tides from overflowing the Ridham marshes, and in the execution of the work the author provided for damming off the water also in the Kemsley marshes. In this way the area flooded and the quantity of water to be contended with at ordinary tides in proportion thereto was reduced to about 350 acres. The ordinary spring tides rose about 3 feet over this area, so that at high water there would be about 45,738,000 cubic feet of water covering the marshes. The surface was clear in about four hours, so that the average discharge through the sluices and breach was 190,000 cubic feet or 5346 tons per minute.

There were two alternative methods; either piles could be driven across the narrow gap between the end of the pile dam still standing and the opposite bank; or an inset wall could be carried some distance up the Cold Harbour Fleet or main drain of part of the marshes discharging through the gap, and building up a dam composed of bags filled with ballast across the Fleet. The subsoil in the drain was found, as has been said, to be very soft and treacherous, and although at low water the plan of piling looked simple enough, the author considered there would be less risk in forming the inset wall. Another reason also for this opinion was that at the piled dam the whole of the water flooding the marshes must, at the fall of the tide, pass through the gap unless large additional sluices were built at various places through the old wall lower down the river. On the other hand, by forming a new inset wall some distance up the Cold Harbour Fleet, opportunities would be afforded of putting in sluices much more easily and economically. Moreover in forming such a wall there did not appear to be any necessity for piling, which can be undertaken only during low tides, and is a slow operation.

The work began in May 1899, with a wall (Figs. 7 and 8) on the south side of the Fleet and on the line of one already begun by one of the landowners. At the east end of this work a sluice 3 feet square was put in to take the water from an old creek draining the Kemsley marshes. At a point further westward another sluice 3 feet square was laid, and a drain cut round the back of the new wall to receive and discharge the water from the Fleet which, when the dam had been made across it, would otherwise have had no outlet. A sluice, 3 feet square, was also laid, at a higher level than the other sluices, under the wall which was commenced on the north side to join the wall near the piled dam. This sluice discharged the water which flowed towards the old drain at the back of the wall by

the river. There was also an old sluice through the wall by the river that discharged water from the back drain. Thus there were four points at which some of the water flowing over the marshes could be discharged and diverted, to some extent, from the work during its progress. The wall on the south side was then carried on to a point at which it was intended to cross the Fleet. The wall was raised about 4 feet above spring tides. The remainder of the wall on the north side was not attempted until the dam across the Fleet had been raised so that the flood-water could escape on a surface where it could do no harm. It was found, as at Northey Island, that the rush of the water over the surface of the marsh caused no abrasion provided it had room to spread.

While the south wall was being formed, preparations were being made for the construction of the dam. The cross section of the Fleet, and the softness of the soil in the centre of its channel, suggested the convenience of sinking a barge. Bags filled with ballast, a quantity of Kentish rag-stone, rough stakes about 6 feet long, and a number of bundles of fagots were brought to the spot. A wall about 20 feet long, and about 4 feet above spring tides, was formed in the line of the dam on the north side of the Fleet. An apron, about 20 feet wide, consisting of bundles of fagots staked down, was laid in the centre of the channel of the Fleet, just in front of the proposed site for the barge, and entirely prevented scour of the soft bottom of the channel when the tide ebbed.

One barge was then sunk in the centre of the channel, and filled with Kentish rag-stone and earth, and just where the barge was sunk, the foundation of the dam was first made. It was about 6 feet high and 60 feet long, and on the downstream side was faced with bags of ballast, which formed a slope. Another barge was also sunk a few feet away from the first barge. On this foundation the wall was then raised, as the tides served, another 4 feet, and about 35 feet broad. It was still faced, and the top surface was temporarily covered with bags of ballast, so that the spring tides, during which nothing could be done to the dam, should not scour out the clay. As the tides fell again, the wall was still further raised, and also joined with the south wall and with the short length of north wall, until the top was about 15 feet above the channel of the Fleet, and 4 feet above high-water spring tides. During the building up of the dam, some scouring took place, as at Northey Island, of the broken sides of the Fleet, but the sides were protected by laying bundles of fagots and Kentish rag-stone on them.

The dam having been made safe the rest of the work was

simple, as it only remained to fill up the gap of 100 yards in the north wall, which was all on high ground over which the spring tides rose about 4 feet at spring tides, and from 1 to 2 feet at neap tides. The surface of this high ground was not affected by the scour except at one point. As soon as the tide was prevented from flowing up the Fleet, the scour then confined to the north side immediately commenced to work upon the point referred to, and in two days swept out a channel about 6 feet deep and 15 feet wide, right across the proposed line of wall on the north side. This, however, was easily stopped, the wall was completed, and the tide shut out on September 1, 1899. So far the work had been carried out without any hitch.

On September 18, however, at the time of high spring tide a gale sprung up and the tide washed over the new walls, and at the point at which it had cut the new channel the wall gave way. A small barge was then sunk in the channel, the gap again closed, and the tide shut out once more. But within a week, during the next spring tides, the gap was again opened and the barge washed out and broken to pieces. Two or three more attempts to close the breach also failed, and the new breach became larger and much more difficult to close. It then became apparent that the line of an old creek had been crossed, and this was confirmed by a reference to old maps, although, when the work was commenced, there was nothing to indicate it except a slight depression of about 4 or 5 inches on the surface of the ground on that side of the Fleet.

The author then determined to form a new inset wall on the high ground round the upper end of the channel cut by the tide. This was carried out, and the tide was shut out again on November 25, 1899, or just two years after the sea had overflowed the land. The outer slope of the inset walls was then faced with Kentish rag-stone to protect it from the wash of waves during gales.

The cost of the work, including 600*l.* expended on the stone facing, amounted to 3200*l.*, not an excessive expenditure considering the area and character of land reclaimed.

Conclusion.

There are within the author's knowledge several other breaches, caused by the high tide of November 1897, still unclosed. Some of these will probably remain so and the land will go to sea. In any case they will be widening and, therefore, the difficulty of closing must be increasing.

From instances given, some general principles may perhaps

be deduced, but no rules can be laid down. The circumstances as regards situation, area flooded, subsoil and rise of tide differ in every case, and the conditions of the tides, the height of which is much affected by the wind, are factors by which alone the opportunities of closing may be judged. At both Northey Island and Cold Harbour Marsh the work at the dam at a critical time had frequently to be postponed for several tides, owing to the unexpected height to which they were driven up by the wind.

But while no rule can be laid down, some lessons may be learnt from these records. Three different methods of closing breaches have been referred to, viz. by piling and planking up, by sheet piling and the erection of frames to receive panels which can be let down and quickly backed up; and by making an inset wall and dam round the breach without piling. All these methods have succeeded, although there is always risk of failure. But in adopting any one of these, especially in the case of small areas of agricultural land from 200 to 1000 acres, the engineer is handicapped by the question of cost.

The late Mr. George Webb mentions a case in which he enclosed 100 acres at a cost of 25*l.* per acre. The land, fifteen years afterwards, was worth, he says, about 20*s.* per acre. Elsewhere he describes the difficulty of stopping the rush of water in closing the embankment across two rills 200 feet and 250 feet wide respectively, and states that, owing to this difficulty, the cost of enclosing 250 acres was 19,000*l.*, the stopping of the rills alone absorbing 10,000*l.*

The condition of marsh land, after it has been reclaimed for many years, makes it more difficult to stop a breach in the wall round it than to close the wall when it is first made, inasmuch as inside the wall land has sunk 3 or 4 feet, so that, if the sea breaks in, nearly every tide will overflow the surface more or less. The land of most old marshes will be found to vary in level from 7 to 9 feet above Ordnance Datum, and the saltings outside will be from 10 to 11 feet. No land should be enclosed until it has risen to a general level of at least 11 feet above Ordnance Datum.

Unless the area is so large that the system of piling and panelling adopted in stopping the middle level breach can be applied, the author considers that the inset wall without any piling is the cheaper, and therefore best adapted to the circumstances of a comparatively small area. Driving piles across the gap has the disadvantage of being slow work, and, further, in narrowing it, and thereby increasing the scour, it might be said that, without extraordinary precautions and extremely good

luck, the piling advanced to its own destruction. And not only this, but as already pointed out, the whole quantity of the water flooding the marsh must pour through at each ebb and flood tide.

The author considers that the late Mr. C. B. Vignoles, past President Inst. C. E., concisely stated the true principle when he spoke on the closing of reclamation banks in January 1864, as follows:—

"The method to which he alluded, which he himself had executed with success, was to close the breach horizontally by gradually shallowing it from the bottom of the opening, watching the progress of the ebb and flow through the breach, fortifying each layer of material as it was laid, and so gradually filling the breach. When the closing was executed vertically, which must always be done in a more or less rapid manner, there was considerable danger from the rush and velocity of the water, the velocity being in proportion to the narrowness of the opening; but by raising the bottom the velocity, so far from being increased, was diminished."

The author in closing the breaches under notice endeavoured to follow this principle, at the same time not losing sight of those enunciated by Captain Perry, already referred to, as to sluice capacity and depth, to the importance of making the foundation watertight, and constantly shutting the sluices down to pen the water when it had ebbed to the level of the height of the dam as it was raised.

ADDENDUM.

Stow Maries, River Crouch, Essex.

The work on the third of the breaches to which the author alluded in the early part of his paper, having been completed, he has pleasure in adding the following particulars. The breach occurred in a wall on a tributary of the river Crouch in Stow Maries parish, Essex.

The area flooded through this breach was 500 acres, and in addition to this a large area lower down the Crouch was submerged owing to other breaches, the tidal water flowing freely from one area to the other. A short embankment, however, stopped the flow from the area below on to the marshes in Stow Maries parish, so that the quantity of water flowing through the breach under notice was limited to that which entered it and covered the 500 acres.

As in the other cases described, the breach occurred opposite a drain, perhaps about 15 feet wide at the top, although there was no sluice at that point. No attempt to repair the breach was made from the time—November 29, 1897—the tide broke in until July 1899, when the author was instructed to proceed to close it. By this time the drain had widened to 70 or 80 feet at its lower end, and 50 feet at its upper end, in a length of about 250 yards. An inset wall round the drain was then commenced. No serious difficulties were met with, the soil being much stiffer and stronger than that either at Grovehurst Beach or Northey Island, and less liable to abrasion from the tide. Sluices were put in where drains were crossed, and the wall, which was about 590 yards in length, was ultimately completed and the tide was shut out on March 26, 1900.

DISCUSSION.

The PRESIDENT said he wished to propose a very hearty vote of thanks to Mr. Grantham for the admirable paper which he had just read. Difficulties, both little and big, cropped up in connection with works such as the paper described, not only when they were expected, but when they were not expected, and they caused much difficulty in keeping notes of what took place; therefore, when the Society could get such a paper as the present, they ought to be doubly grateful for it.

The first thing which struck him in the paper was the enormous quantity of water which passed in and out at the rise and fall of the tide through the openings caused by the breach which was made in the first instance. When they considered the enormous weight of the water which passed in and out over a soil which probably was not of the hardest or strongest, they would have a very good idea of the great amount of power which was exerted in the enlarging of the breach. When a wall was built of piles and put in, the pressure upon the sides of the wall, both inside and outside, until the wall was completed, and as the final breach was being closed up, was very considerable. It had occurred to him that the only way was to leave a large number of sluices which could be shut down when the final breach was closed. These were no doubt very difficult to form and rather expensive. The author had given three different methods of closing the breaches. He first of all mentioned piling and planking up, but that method had not been quite as satisfactory as some of the other methods which the author adopted later on. That rather bore out what he

(the President) felt some years ago when he read a paper on pile driving, in which he tried to point out the fact which he had noticed very particularly, namely, that the side strength of piling was not nearly so great as was commonly thought, and that when a pile was being driven the nature of the ground around it had a very material bearing upon the final blow upon the pile, because, if the ground was of a soft nature, the pile had not much side resistance. Of course, in those instances where the ground was comparatively soft, and was being further softened by the scouring of the water, the resistance of the piling must be considerably reduced.

He would ask Mr. Grantham a question with reference to a statement in the paper that the cost of reclaiming about 100 acres of land was 25*l.* an acre, and that afterwards the land was worth about 20*s.* an acre. Did Mr. Grantham mean that the land was 20*s.* an acre to buy outright, or worth a rental of 20*s.* an acre per annum? The difference between the two would make a considerable difference with regard to the question of whether it was or was not worth while to reclaim the ground.

Mr. Grantham, replying to the President's question, said that the statement he had made was quoted from a paper by the late Mr. George Webb, read at the Surveyors' Institution, and he was not quite sure what Mr. Webb meant—whether it was 20*s.* an acre as rental value, or 20*s.* an acre for the fee simple. [Mr. Grantham has since ascertained that 20*s.* per acre was the annual letting value.]

Mr. R. G. Allanson-Winn said, that in the early part of the paper allusion was made to the breaking away of a wall through the drying of the clay on the top causing fissures. He had been a sufferer from the same trouble. He had a wall at Glenbeigh, in Ireland, which was built in 1820, by one of his predecessors, for the purpose of reclaiming 400 acres of very valuable pasture land from the sea. The difficulties were considerable. The course of a rapid river had to be diverted, and a sea wall had to be built across sandbanks which were very unsound in some places, and were intersected by several deep shifting channels. The tide flowed deep and rapid, and the mountain waters poured down suddenly over the space to be enclosed. There were no means to be employed in the construction of the wall but native labour, unaided by machinery of any kind, and that labour was given by the inhabitants of the district. The wall, or embankment, was composed of peat or boggy stuff rammed and trodden down by large numbers of men. It was situated on the south coast of Kerry, and that was a very wild place at the time the work was undertaken,

and labour was obtained at 4*d.* a day. Therefore it was a comparatively easy thing to get large quantities of material shifted from place to place at a small cost. The slope towards the sea was three in one, and two in one towards the land. Both sides were pitched with stone, greater care being taken with that portion which faced towards the sea. There was no direct opposition by the open sea, but there was a considerable amount of back-water which was liable to be lashed into somewhat severe waves if there was a storm from the east; but storms from the east were very rare, and consequently the engineer did not anticipate any danger. He did not think, however, that the wall had been built quite high enough, or that sufficient allowance had been made for extraordinary spring tides and extraordinary winds possibly occurring simultaneously. After a very dry summer when the top of the peat had become cracked and spread into fissures, a very high tide occurred, and the water poured over the top. That was about 1836 or 1837. The old inhabitants of the place stated that they saw the water pouring over the top, and gradually pushing out the back part of the wall, which, as he had said, had not been pitched or built with so much care as the other portion. The breach was then formed, and the tide came in over the very nice pasture land which he had been told would be now worth from 2*l.* 10*s.* to 3*l.* an acre per annum, if reclaimed. Now the question was, how best to repair the wall. He had estimated that the filling in of the breach and strengthening the wall all the way through, and putting in the necessary sluices, would cost about 5000*l.* The wall was three-quarters of a mile long, 15 feet high, and about 6 feet wide at the top.

The four points which had struck him in connection with the paper were, firstly, the dryness and uneven shrinking of the material with which the bodies of such embankments or walls were constructed; secondly, the necessity of having a puddle core in cases where it was impossible to build with proper masonry and concrete; thirdly, the danger there was in trying to avoid expense by making embankments of that description too low, that is, not giving a very ample margin for a possible high tide and the simultaneous occurrence of unforeseen circumstances; and, fourthly, the method of building up the gaps. His opinion was that breaches such as he was speaking of ought to be built up in horizontal layers of about one foot at a time, and built very well with hydraulic cement, so that each tide could flow over, and another foot be laid when the tide flowed back again, right away along the whole length of the gap until the top was reached. That was his plan for repairing the wall of

which he had spoken, and he hoped, by the introduction of some clay into the upper portions of the work, and by increasing the height and width, to avoid the recurrence of what had happened before and to prevent the possibility of the water getting into the upper fissures or cracks.

Whether the gap was caused partly by the bursting up action of the water he did not know. He rather thought that it was caused in the same way as in Mr. Grantham's wall, namely, by the water getting in at the top and tearing out the back portion. Of course, in the case of water running through a gap of about 200 feet wide and 20 feet deep, and flooding 400 acres of land, as was the case at Glenbeigh, the rush was terrific, and he should be very much afraid that it would be almost impossible, without incurring great risk and expense, to put in coffer dams. The building up in layers seemed to him to be the best and most satisfactory method of dealing with all gaps of that description.

Mr. L. F. Vernon-Harcourt said that Mr. Allanson-Winn had alluded to a sea embankment made with peat. Peat was a very bad material for an embankment, even where it was only a question of flood embankments alongside rivers; and certainly for tidal embankments, it would be very desirable to get some material that would have more consistency than peat, peat being merely a fibrous material which readily allowed the infiltration of water. Another matter mentioned by Mr. Winn was the overtopping of a reclamation embankment. All engineers knew that if an embankment of any description was overtopped to any extent by the rising water, the inner slope of the bank was sure to be scoured away by the rush of water down it, and that, therefore, eventually a breach would be formed through the weakened embankment. That action had been frequently witnessed in river and sea embankments. The only way of preserving an embankment subjected occasionally to such conditions, would be to have its inner slope pitched Mr. Winn had referred to a sea embankment which had been thus pitched to a certain extent, but not solidly enough to bear the scour of the wave breaking over the embankment and rushing down the inner slope.

They were very much indebted to Mr. Grantham for having brought the present subject before them, because he had shown them a way of closing breaches, by putting in inset embankments, which would not have occurred to everybody. One advantage of the method was that they got a greater length of embankment over which the tide would flow in and out of the enclosed low-lying lands more quietly in proportion to the

length, during the gradual raising of the embankment. Another advantage was that, although there would be a considerably greater extent of embankment to be built up, it was possible to build it in a much more solid manner on undisturbed ground, than on a foundation across the base of a breach where the bottom was very irregular, and had been exposed to a powerful tidal scour since the rupture of the bank. Then, again, there was the advantage that they could put in sluices, if necessary, at different points further apart and more safely in the much longer length of inset embankment, than in the comparatively short and less securely formed embankment straight across the breach.

He was quite in agreement with Mr. Winn that the embankments closing breaches ought to be brought up in horizontal layers, the layers being formed merely of the thickness which could be brought up solidly right across the breach during a single low tide. It had often been attempted to stop breaches by collecting a large quantity of material, and tipping it in as rapidly as possible on each side, like a railway embankment, in advance of the rising tide; but very often indeed that arrangement had failed, simply on account of the great scour which occurred to an increasing extent as the breach was narrowed on each side by the advancing bank.

One of Mr. Grantham's photographs showed the embankment being made, the inner side being, as it appeared, free from water. It seemed to him that when they were bringing up a bank of that kind, and if the water rose over the bank, and flowed into the enclosed space as the tide rose, which apparently was the case in that instance, it would clearly be an advantage, if it was practicable, to keep the water in on the inner side up to the level of the bank, so that there might not be a rush of water into the interior space when the tide overtopped the bank. That seemed to him to be the principle which was desirable in all these cases. He had been informed by Sir Leader Williams, with regard to the construction of the Manchester Ship Canal, where there were several long lines of embankments for reclaiming small embayments in the Mersey estuary, and shutting off the canal from the estuary, which had to be made in a tideway, that all of these embankments had been brought up in horizontal layers, and that none of them had been tipped out from both ends so as to form a narrow gap just before they met. It seemed to him to be a fundamental principle to try to avoid as much as possible having a great scour of water coming in from a rising tide over a bank, or through a gap, and pouring over a large area through a narrow opening into a lower level.

The only way in which it seemed to him to be possible to avoid that result, was by retaining the water inside, as far as possible, up to the level of the bank; and then any tide overtopping the bank came in with only a comparatively gentle flow over the bank.

The descriptions of the breaches given in the paper furnished a remarkable confirmation of the principle which would be endorsed by all engineers who had had experience of structures exposed to the sea, that injuries to sea-works should be repaired at the very earliest possible opportunity, as waves at tidal scour rapidly enlarged any hole or breach that might be formed.

Mr. W. Whitaker said, it appeared to him that the author preferred a flank movement round the breach to a frontal attack. The paper had reference largely to Essex, and so he would call attention to some papers in 'The Essex Naturalist' recording the effect, at Canvey and other parts, of that particular storm to which the paper referred. He must object to one heading in the paper, namely that of "Northey Island." The word "Northey" itself meant "North Island." He (Mr. Whitaker) knew fairly well all the spots which had been described in the paper, and he remembered being at Northey some years ago and finding that it differed from Canvey and other islands, for in the centre of the island there was rising ground which was well above flood, so that there was a real respectable core to the alluvial land. Before the paper was read it occurred to him that it was very often a question whether the land that was recovered would pay for the work done. Of course, the low-lying lands were valuable for pasturage, because they never dried up, and so there was always pasture to be found upon them. Another point which struck him in the paper, and which he was always pleased to see, was that the author had recorded failures. Records of failures were often rather more important than records of successes, and he was always glad when engineers recorded their failures, or that, if they did not record their own failures, they at all events drew attention to those of others.

Mr. Charles Martelli said, that in his capacity of a trustee for an Essex farm estate, he had had his life made a burden to him for something over two years in consequence of a breach of the protecting wall of his estate on the river Crouch. The farm was situated a few miles above Burnham, and in the November flood, to which reference had been made, 70 acres of his farm were flooded, and about 200 acres of the farms of his neighbours were flooded. Within a week of the disaster, he communicated with the adjoining owners, and his client and

another owner agreed to form a fund to reconstruct the wall. The interest of his neighbours consisted of the fact that their land depended for its safety upon his wall. Another of the adjoining owners was so long in making up his mind to take part in the work of rebuilding the wall, that it was not until nearly the middle of August that the order for the work was given to the contractor, too late in the year, of course, for the commencement of an undertaking of that kind with a fair chance of success. The contractor who was selected proved quite unfit for the work, and he "threw up the sponge" almost before he had started upon it. Within forty-eight hours of signing the contract, he reported that he was unable to get sufficient labour as the harvest was coming on. The tenant of his (Mr. Martelli's) farm was a Russian or Pole, and a man of energy, and he volunteered to supplement the contractor's labour supply by engaging a large number of his own compatriots, Russian refugees from the East End of London. A small Muscovite army accordingly came down from Whitechapel, to the assistance of the English workmen, and bivouacked on his (Mr. Martelli's) farm. This allied force amused themselves under the guidance of an eminent engineer and a clerk of the works for some months, until they had spent some 800*l.* of the money. The sponge was then again thrown up, and the contractor declared himself to be on the eve of bankruptcy, and stated that nothing further could be done. The Russian tenant attributed the failure of the enterprise to the fact (alleged by him, with what truth he—Mr. Martelli—knew not) that forty barrels of beer had been consumed by the Englishmen during the work upon the wall. The Englishmen concerned attributed the failure to the fact that the Russians did not drink beer, and that they were consequently not strong enough for the work. The wall was now very nearly level with the original level of the fields, and the breach, which was originally about 30 feet wide, was now enormously enlarged, and there were about 300 acres of the best land at the bottom of the river Crouch at most of the tides. This morning he sold the fee simple of the farm for which he was trustee, comprising 230 odd acres, for 425*l.* to the Russian tenant. That person intended during the following week to start the building of a fresh wall. He had said that the wall would be up before the summer, and he had invited him (Mr. Martelli) to go down in August to see it. He believed that the Russian farmer was going to adopt the plan of an inset or a counter-wall. There were, or had at one time been, several walls of that character on the neighbouring land. His (Mr. Martelli's) clients considered that he was responsible for the breach of the wall, in consequence (they

said) of his not having sufficiently topped it from time to time, and he had been threatened with the punishment which was awarded in medieval times to those people who omitted to keep up their sea walls for the protection of themselves and their neighbours, and which punishment was described in 'Hollinshead's Chronicle' (A.D. 1577), in the following terms:—"Finallie, such as having wals and banks neere unto the sea and doo suffer the same to decaie (after convenient admonition) whereby the water entereth and drowneth up the countrie, are by a certeine ancient custome apprehended, condemned, and staked in the breach, where they remaine for ever as parcell of the foundation of the new wal that is to be made upon them, as I have heard reported."

Mr. R. Robinson said that before some of the difficult work described in the paper was undertaken, he had the pleasure of accompanying Mr. Grantham to Port Victoria, a spot near the breaches referred to, where similar troubles of minor importance had occurred.

At the same time, as Messrs. J. Aird's representative and for Mr. Hickman Barnes (engineer to the Levels), he had some serious breaches to close on the Thames between Purfleet and West Thurrock; he succeeded with that work in much the same way as Mr. Grantham had done. An inset wall or half-tide dam was made with bags of clay and ballast, etc., 15 to 20 feet wide, and to a depth of from 3 to 7 feet above marsh level. Stakes were driven at each side of the dam, and the bags were weighted with old railway metals, which were again under chains, these being lashed transversely from stake to stake to prevent demolition. The temporary dam being completed, the breach was then attacked. Sixteen freights of Kentish rag were dropped on the river side of the same (slightly in front of the outer line of the bank); behind that, bags of clay; at the back of that again, clay in bulk, all built up horizontally. He did not have any mishaps.

It was suggested to him that he should sink barges in the breach, but he had had enough of barges, inasmuch as a barge was the original cause of the main breach. The bank had split in the way described by Mr. Grantham, and the tide overtopped and broke it away. Some barges which had been moored a little way off in the river, broke their moorings, one of which settled on the top of the bank. The outward and inward scour went under and round the barge, and within two or three tides the breach was 130 feet across the top, and about 35 feet deep.

The area of marsh and cultivated land (with several rows of houses and large oil stores upon same) was nearly 1000 acres.

It could well be imagined the terrific rush of water which was constantly flowing chiefly through that one breach. His first visit to the site was on 2nd December, 1897. The tide was effectually kept out on Christmas Eve of the same year. The flood-water then had to find its way through two sluices. The engineer inspected and passed the work as completed satisfactorily on the 14th February, 1898. That was some time after the work had been finished and all the plant removed. Over 500*l.* worth of sugar bags were used on the work.

Mr. R. J. Bevil Sharpe said that, as Deputy Engineer of the Ribble Navigation, the paper had been one of peculiar interest to him. He could endorse what the former speakers had said about raising the wall by layers, instead of from each end. In November last year, there was a heavy flood in the river Ribble, of the same kind as the flood down south, and a large portion of a bank which reclaimed land on the estate of Mr. Rawsthorn was washed away. The owner endeavoured to close it by tipping by the hand from each end, and he had nearly 300 men at work on the breach. He (Mr. Sharpe) told the owner that he would not succeeed in that way, and he recommended him to get a number of bags of sand, and some brushwood, and start at neap tide by making foot layers, and to let the tide rise over the bank until it was topped up, and close it at the next neap tide. That method was tried, the work was done, and the bank had stood all the winter. He would ask the author whether the cost of the inset walls would not be much greater than the cost of repairing the breach in the first instance.

Mr. Harry G. Assiter, referring to the question of what was meant by the price of 20*s.* per acre for the reclaimed land mentioned in the paper, said there was little doubt in his mind that the 20*s.* must be the annual value. At that rate the value in fee simple of the land would probably be about 35*l.* or 40*l.* an acre, which, of course, was quite low enough if it cost 25*l.* to reclaim it.

With regard to the question of cost of constructing and repairing sea-walls, it appeared to him that very often the serious breaches that were made in sea-walls protecting land became to some extent really a national question, and it was quite within the bounds of possibility that landowners and those who were responsible for repairing walls were not always the greatest sufferers from defects, and that either from want of funds or from want of interest they might leave the walls unrepaired. It seemed to him that, in such cases, landowners ought to be able to get money from some national or public fund, and that the cost of repair should be made a charge upon

the lands so benefited, so that the work could be done without the landowner or the person responsible for the repair of a wall having to dip his hand very deeply into his own pocket.

Mr. Sharpe, referring to the question of the 20*s.*, said that the land of which he had spoken was let at 40*s.* an acre.

Mr. W. H. Holttum asked whether the author would favour the meeting with cross sections of the walls, so that some idea of the value of the materials, and of their stability, might be formed. With regard to the practice of throwing bags of ballast without cement into the water, it must be remembered that some day the bags would rot, and existing interstices would be thus closed up, accompanied by slight movement, which might prove very detrimental to the whole mass. He thought it would be interesting if the meeting could be assured that the walls, in actual construction, were provided with such a sufficiency of slope, and margin of stability, as to render this consideration of no consequence.

Mr. H. W. Towse said there was one point which he could not understand, and that was with regard to the sinking of the barge in one of the fleets or drains which existed on the land which was flooded. He thought he was correct in saying that in the fleets or creeks in the Essex land there was a very great depth of very fine sludge or ooze. In the sinking of the barge, would the weight of the barge when filled with stone be sufficient to make a watertight joint, as a mechanical engineer would say, or to present such friction as to prevent the scouring out of the ooze when the wall was completed and the full water pressure was outside it? It seemed to him that there would be a kind of slipping between any new materials placed in bags or between the bottom of the barge and the ooze on which the barge rested.

Mr. Perry F. Nursey said, he had great sympathy with those who had been troubled with breaches in sea-walls, because he was once afflicted with such a breach himself, but he was glad to say that in the end the affliction proved to be very light in its form. It occurred in 1873 on a hundred acres of land at Benfleet in Essex of which land he had charge at the time, and where he was constructing eight sunk powder magazines. The breach occurred in a wall about 12 feet high. He was suddenly wired for, and hurried down by the next train in a state of considerable anxiety, but on arrival he was glad to find that the breach had been nearly closed. It took place during very hot weather, the wall being seriously fissured, and it was discovered by his ganger, who was a good wall-man. He had already got some men together, and by cutting away weak

spots, puddling, and driving stakes, they managed to fight the tide inch by inch, and fortunately there was no damage done. If, however, the breach had not been stopped in time, it would have been a question of several thousand acres of land being submerged.

The following communication from Mr. ALEXANDER BEAZELEY, who was unable to be present at the meeting, was then read by the Secretary.

The usefulness of this paper is much increased by the fact of its containing a description not only of the methods that were crowned with success, but also—as at Brading, Northey Island and Grovehurst—of those in the first instance attempted, which failed, together with the reasons of their failure. It is always pleasant to hear of success in our works; but there can be no question that records of reverses, though less agreeable, are in their way equally instructive; because methods that in one instance may have failed, have in others succeeded, and the very causes of their failure bring out clearly the features rendering them specially suited for employment in particular situations and under particular circumstances.

Regarded simply as an opening through which the tide in its flow and ebb alternately fills and empties the embanked area, there appears no reason why a breach should present more difficulty in the matter than do the openings customarily left in a new bank during construction. But whereas such openings are of a dimension so calculated as to obviate scour, and are (or ought to be) provided with flooring, aprons and side-guards, breaches are always destitute of these, and frequently are of less width. Where the width is insufficient and the earthwork of the bank strong, the result is a deepening of their bed by scour, and hence the enhanced difficulty and expense of closing them.

Judging from the plans given of Northey and Grovehurst, it would appear (although not stated in the paper) that the breach occurred at the site of a sluice. If so, this doubtless added to the difficulty attending the work of repair, since the confluence of drains at that point must have greatly complicated matters.

Besides the three methods of closing referred to in the paper, a fourth one has in many cases been employed with advantage—that, namely, of raising the floor of the breach itself by mattressing and loading. Of the three former, that of an interior cradge or inset bank appears in the case of Northey and Grovehurst to have been preferable; and it would be instructive to have details of the manner in which these banks

were constructed. Mattress-work and clay loading, carried up horizontally over the whole length (a sluice if needed being first built) is generally regarded as the best mode of proceeding. Another point upon which information would be interesting is, the circumstances which rendered necessary so great a length of inset bank at Grovehurst as compared with that which sufficed at Northey.

In addition to information on its titular subject, the lessons to be learned from the paper are:—First, the need of careful inspection of sea-banks and constant attention to their maintenance. Second, the desirableness of promptly taking in hand the repair of a breach, every hour's delay involving further injury and increasing the difficulty and cost of making good. Third, the importance of height in the bank and in the earthwork or other closure put in by way of repair. Examples illustrating the danger of neglect in this respect are to be found in what is stated concerning the works at Brading and Grovehurst.

The paper is one of much interest, and Mr. Grantham is to be congratulated on having made a valuable addition to the somewhat scanty existing record of works such as those of which it treats.

Mr. Grantham, in reply on the discussion, said that there seemed to be a general consensus of opinion as to the horizontal closing of a breach rather than the vertical. That was the method Mr. Vignoles recommended many years ago, and there was no doubt that it was the safest way of working. Mr. Beazeley in his communication asked whether there was any sluice at the point of the breaches in Northey or at Grovehurst. There was no sluice at either place. It was rather peculiar that the banks should give way just opposite the drains. As to the use of mattressing for closing breaches, the Dutch had practised that method to a considerable extent, but he did not think that they would have done any better if they had used it in the present cases. In the first place skill was required, and it was necessary to get men accustomed to the work, or a great deal of time would be wasted, and he did not think that they would find suitable land for it in that part of the country. Nor did he think that by that method they would have saved any money or have been more successful. Mr. Beazeley compared the length of the inset wall at Grovehurst with that of Northey. There was a very marked difference between the lengths. The first was 265 yards long, and the wall at Grovehurst was nearly 700 yards, but Northey had only 200 acres and Grovehurst had 900 acres flooded; and at an extremely high spring tide they might always expect to have to deal with quite 600 acres at

Grovehurst, so that it was necessary to leave a larger space in order that the great quantity of water might spread more smoothly over it while they were making a dam across the most difficult part. If the water was confined to too narrow a space over the high land there would be such a scour that great risk would be incurred of cutting out a creek. That was the reason of the difference between the two cases.

Mr. Allanson-Winn was undoubtedly correct in saying that for such tides the walls were not high enough. That had been the fault of the walls all round, and it had been at the bottom of the mischief throughout. If a landowner had a long length of wall it was a considerable expense to him to keep raising and repairing it, and the question was whether he would incur the annual expense or run the risk of a breach. He always thought it would be found that the raising of the wall to a standard height was the cheaper plan. Certainly the owner would be saved a great deal of anxiety as against running the risk of a breach. It was most dangerous for walls to be too low. The maximum height of high flood tides round Kent and Essex was well known, and it was very easy to see how much higher walls ought to be. It was all a question of raising them to the extent of about eighteen inches or two feet every few years. In the case Mr. Allanson-Winn had mentioned, he (the author) suggested that bags of ballast might be laid in the heart of the wall. They would strengthen it, but, of course, they would not make a peat wall watertight, as peat was a porous material; but if there was an inclination to leak they would prevent the particles of peat being carried right through the wall, and, therefore, the direct flow of water through would be stopped.

Mr. Vernon-Harcourt mentioned a point which was very important, but there were practical difficulties in the way of carrying it out. He said that it was very useful to pen up the water behind the bank, and he asked with reference to one case why that could not have been done. There was first of all a difficulty in penning the water, and it was impossible to pen it over the whole area of the land, as the men would not be able to get into the land to dig out the clay for making the wall. That difficulty had been constantly met with when the tide was high. Much of the work had to be done during the neap tides, and if they, as well as the spring tides, happened to be high, the men were again shut out. Therefore it would be extremely difficult, except in certain places, to pen in the water behind the bank, even if it could be done at all.

Mr. Whitaker was quite right in saying that he (Mr. Grantham) preferred a flank movement round the breach to a

frontal attack, although the latter might be the best way in some cases. He must apologise to him (Mr. Whitaker) for using the expression "Northey Island." He had not been aware that the word "Northey" meant "North Island."

Mr. Martelli had been extremely unfortunate, but he was quite right in the statement that in former days the penalty for a man who let his sea-wall go down was to have a stake driven through him and to be buried under the wall. No man could now be made liable for his default in neglecting his wall, and the man who kept up his wall well was entirely at the mercy of a neighbour who perhaps did not maintain his wall at all. The case of Hudson *v.* Tabor settled that point. The difficulty was a very serious one. All areas of low-lying land which were not under commission ought to be put under commission with a jurisdiction over a sufficient area. At Grovehurst there was no commission, and what had been done was only done by the co-operation of the landowners. As to the question of beer, that beverage was used upon the works which he had described, and the probability was that not so much as was done could have been done without it, inasmuch as it kept the men to the work.

Mr. Sharpe had asked whether the cost of an inset wall was not much greater than the cost of closing the breach at first. That was just the question. If a breach was closed at once perhaps the work might be done for 200*l.*, but if the breach was left for a fortnight or a month the cost might be 2000*l.* Most of the serious breaches which occurred were allowed to remain until they became very large. The raising of the money for doing the work took time in some cases. As to the cross sections of walls asked for by Mr. Holttum, the walls were made three feet and sometimes four feet wide at the top with a slope of two to one. The cost of work of that kind could not be reckoned by merely the cubic yards of earth put in. If the quantity was calculated, the ordinary price would have to be doubled or trebled to come to anything like the cost.

The point about the rotting of the bags was very important, and he had very often thought of it. Of course, if the bags rotted the ballast would slip out. But in the case of Grovehurst the bags had been covered over with stone or earth so as to prevent anything of that kind happening. Mr. Towse had asked whether the barge and bags remained firmly in their places. Considering that the barge was loaded with Kentish ragstone there was no fear of its moving, and as to the bags, they seemed to take their position and to get down to the more solid soil underneath. He had not found anything slipping.

If the Society would allow him he would add to the paper a note as to the work in Stow Maries parish on the river Crouch nearly opposite to Mr. Martelli's farm, when the work was finished.

Before concluding he might say that no engineer could do work of the sort which had been described, unless he had good clients and good men under him. He had been fortunate in both respects. His clients had supported him in all the difficulties encountered, and he had a contractor who understood the work and who had done it thoroughly well. The credit of the execution of the work at Grovehurst, that in which he had most trouble, was due entirely to the foreman. For a long time the work was in a most critical state, and it was only by the care and diligence of the foreman, in patching up here and doing a little bit there, that the inset wall was kept up. The foreman was to his knowledge several weeks out of bed, and on many nights when the tides were high he was unable to get any sleep. He only mentioned that fact because he should like the merit of the execution of the work there to be put on the right shoulders.

PLAN OF HARBOUR

SCALE 6 INCHES TO A MILE

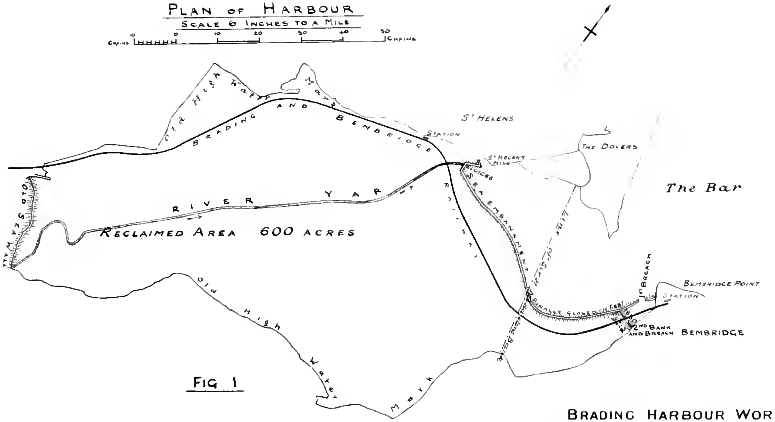


FIG 1

BRADING HARBOUR WORKS.

DETAILS OF DAM.

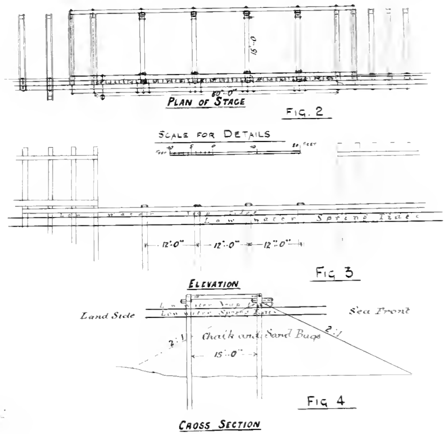


FIG. 2

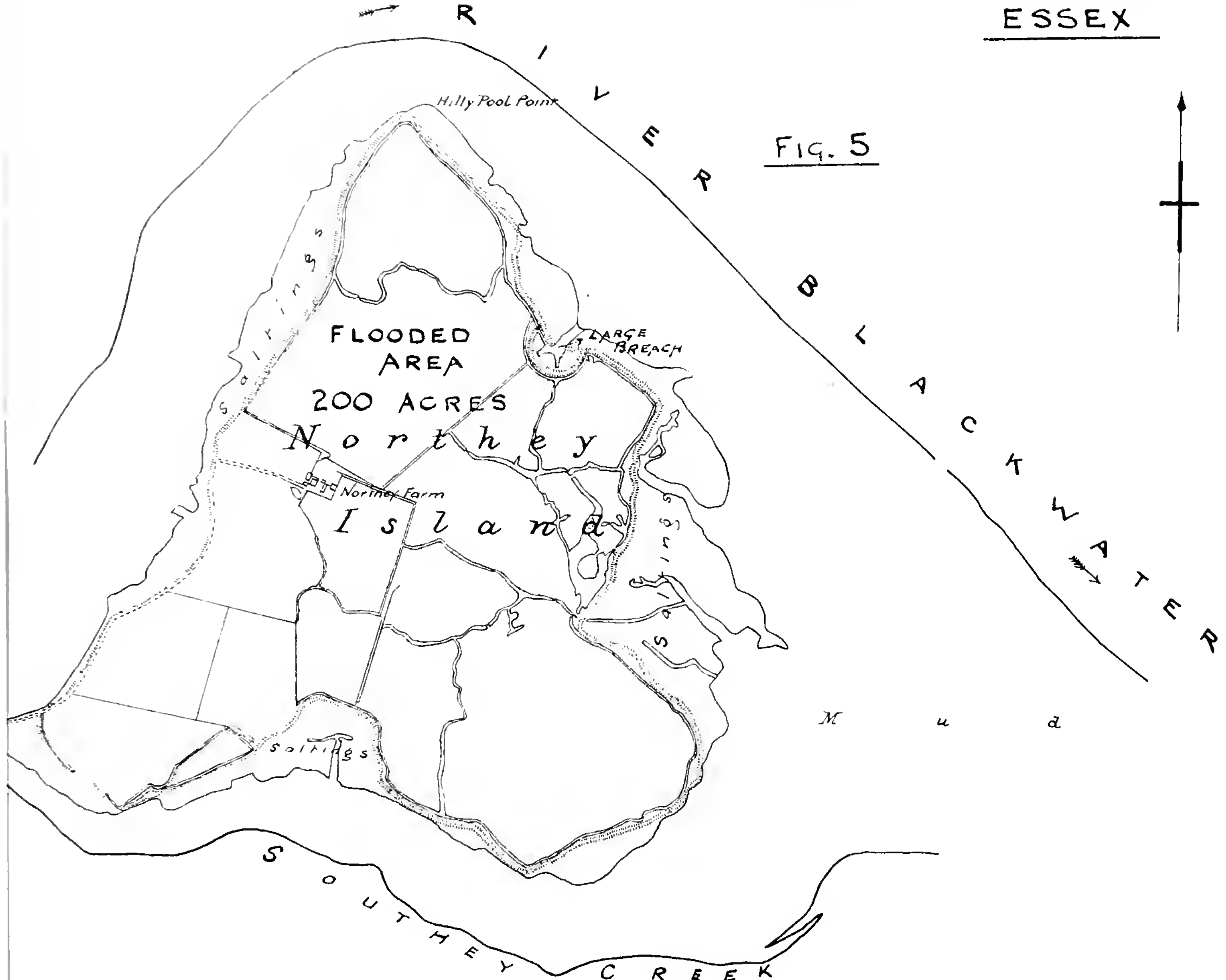
FIG 3

FIG 4

NORTHEY ISLAND BREACH

ESSEX

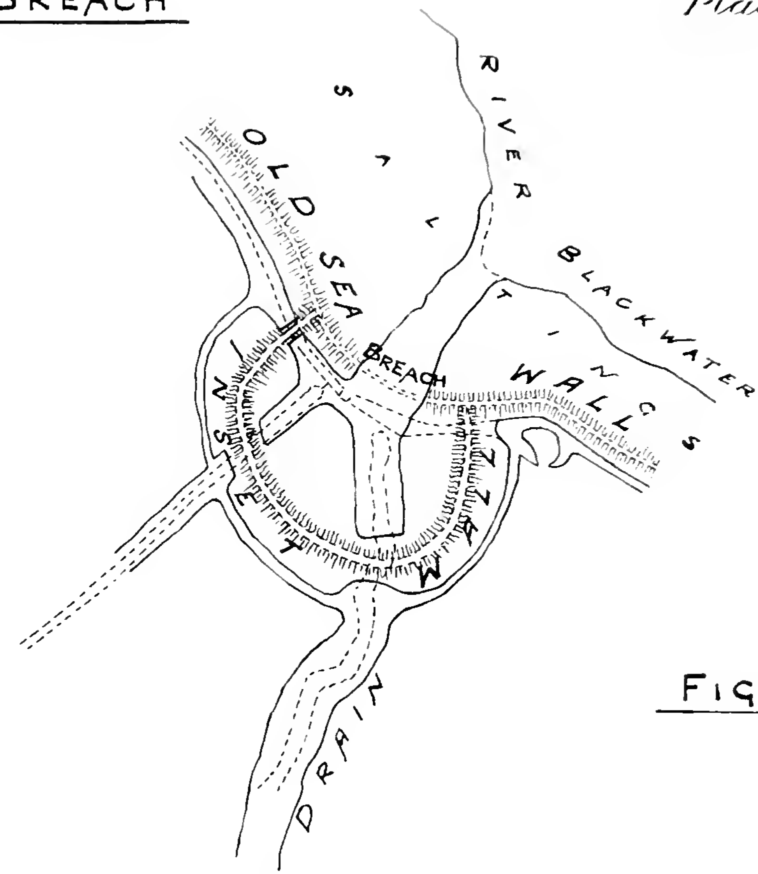
FIG. 5



SCALE 6 INCHES TO A MILE

CHAINS 10 0 10 20 30 40 50 CHAINS

FIG 6



ENLARGED PLAN OF INSET WALL AT LARGE BREACH.

SCALE 25·344 INCHES TO A MILE.

FEET 100 0 100 200 300 400 500 FEET

Iwade . Kent
Grovehurst Breach

Fig. 7

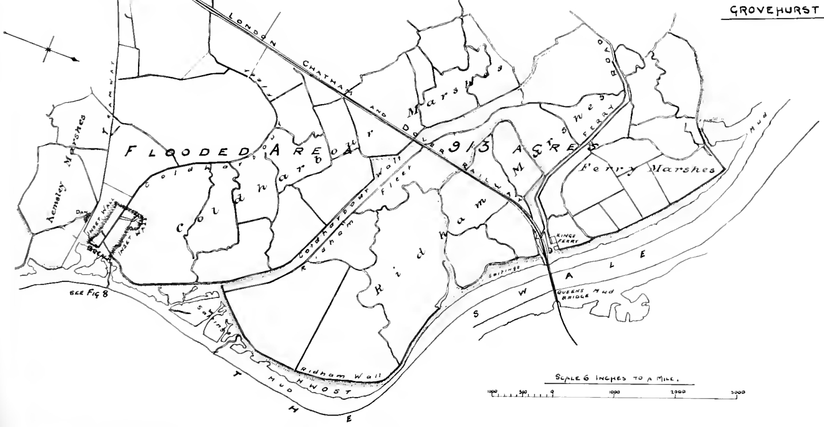
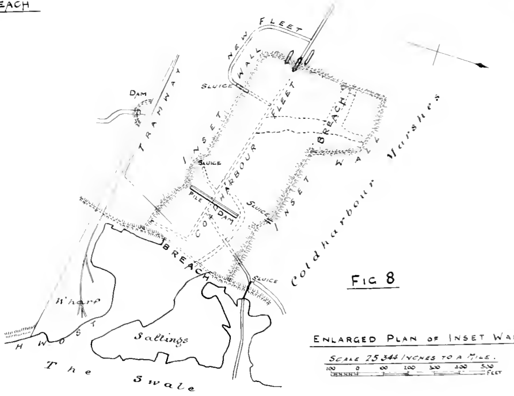


Fig 8



Enlarged Plan of Inset Wall

Scale 25.344 Inches to a Mile.

100 0 100 200 300 400 500 Feet

April 2nd, 1900.

HENRY O'CONNOR, President, in the Chair.

DISINFECTION OF THE MAIDSTONE WATER SERVICE MAINS.

By G. Sims Woodhead, M.A. M.D., and W. J. Ware.

Maidstone (Saxon, Medweyston), the county town of Kent, in the centre of the county, only 34 miles from the Metropolis and 42 miles from Dover, is situated on the navigable river Medway. This river from Tonbridge flows for about fifteen miles in a north-easterly direction; it then flows north-west through some of the most highly cultivated land in the country—the Garden of England. At the bend where it thus alters its course the town of Maidstone is built on the east and west banks, which form picturesque declivities down to the river's edge; it is environed by a country, beautiful, but very highly cultivated. The area of the municipal borough is 4008 acres, and of the parliamentary borough, 4376 acres. In the time of Elizabeth it contained only 294 houses; in 1550 the population in the borough was 2041; in 1781, 5789; in 1801, 8027. It then began to grow very rapidly, and in 1825 had a population of 12,604, in 1861, 23,026, and the estimated population for 1897 was something over 35,000.

On Monday, October 11, 1897, one of us was called in to make a thorough enquiry into the outbreak of typhoid in Maidstone, and to advise the Water Company (1) as to what further steps, if any, should be taken to prevent its increase; (2) as to the cause of the outbreak. With the second part we need not now concern ourselves; what we have had to say on this matter has been reported elsewhere. In connection with the first heading, however, it was evident that certain precautions should be taken at once to prevent, as far as possible, any further dissemination of the disease through the agency of the water supply, should it be found, after due investigation, that this water supply was contaminated.

The reasons advanced for advising this course were: (1) there was a possibility that any infective material that might have made its way into the mains might still remain in some of the pipes, especially in the dead-ends, even after the thorough

blowing out to which they had already been subjected; (2) that although this possibility was small, there existed a necessity to restore public confidence, which could only be done by rendering it absolutely impossible for any infective material to remain in the pipes.

Owing to the fact that the Maidstone water came from three distinct sources, and that one of the waters was distributed to a special area, it was at an early period of the epidemic indicated that the Boarley and Cossington water could not by any possibility be the vehicle by which the typhoid material was conveyed; whilst, on the other hand, it was found that the distribution of the epidemic corresponded with the area supplied from the high-pressure source. If, then, the water had anything to do with the distribution, it was only necessary to sterilise the reservoirs and mains in which the high-pressure water was collected and distributed.

After a careful study of the method of sterilising with dilute milk of lime, as carried out, under Professor Dewar's advice, at Worthing, and of Professor Delépine's experiments on chlorine disinfection, and comparing these with a number of experiments that one of us had carried out with the various chlorine compounds, it was decided that if the arrangement of the mains and service pipes would allow of their being filled with a quantity of chloride of lime solution in a strength of from 1 per cent., this should be done, and for the following reasons:—

1. Chloride of lime is a comparatively cheap disinfectant.

2. Its efficacy as a disinfectant, especially in solution, is of a remarkably high order, this being due, apparently, to a double action of chlorine and of oxygen loosely held in combination.

3. It could readily be obtained in a clear solution of the required strength under the conditions here presented.

4. Because chlorine liquor of this strength, and in the presence of lime, exerts so little solvent action on lead (after submitting lead piping to the action of this solution only one part of lead in 40,000 could be found in solution) no soluble lead is left in the pipes after the first washing out with clear chalk water.

5. It was thought that, although the leather washers on the valves of the taps might be slightly affected, they would still continue to act. As the solution was used of greater strength than was absolutely necessary, the leather, as will presently be noted, did not come very well through the ordeal.

6. The chloride of lime has the very great advantage of being a substance that at once makes its presence known, so that all those through whose taps it was allowed to pass would be fully aware of the fact, and if there were no complaints of

absence of smell from any quarter, it might at once be assumed that the disinfecting fluid had reached the non-complaining area.

7. Because, after the pipes had been once washed out, there could not be the slightest danger of any ill effects following upon the use of this chlorinated water, even though there might be a slight unpleasant acrid taste—a taste which would prevent anyone using the water until the pipes and taps had been sufficiently washed out.

The town and neighbouring parishes of Maidstone have been supplied with water by the Maidstone Water Company under Acts of Parliament dating from 1860. The Company's water is derived from three separate sources, and is distributed on the zone system to three separate areas—a low, an intermediate, and a high-pressure area. The low and intermediate-pressure areas were supplied with chalk-water from Boarley and Cossington sources, whilst the high-pressure supply, to which we have to confine our attention, was derived from the parishes of Barming and Farleigh in the Upper Medway Valley, where numerous springs issue from the escarpment of the Hythe beds (Lower Greensand), directly above the Wealden Clay. There can be little doubt that at certain periods some of this water may have come into surface-relation with the very highly and deeply manured soil of some of the hop gardens. The springs were originally collected and conveyed through iron pipes by gravitation to collecting reservoirs adjoining the pumping station at Barming. It was then pumped through a 12-inch rising main to one of two reservoirs on Barming Heath—one 240 feet above O.D., the other 260 feet—from which it gravitates to all the outlying districts in the high-pressure zone.

It was evident from the distribution of the pipes and from the large quantity of fluid that would be required, that it would be necessary to carry out the operations in two sections, and it was decided to deal first with what may be called the urban section (A) and secondly with the rural section (B). (See accompanying plan.)

Section A includes the Company's high-pressure service reservoir, and the whole of the distribution mains in the high-pressure area north-east of the service reservoir, namely:—

950	yards of	$2\frac{1}{2}$	inch	mains.
13,993	,,	3	,,	,,
3377	,,	4	,,	,,
4957	,,	6	,,	,,
2660	,,	12	,,	,,

Total 25,937 yards, or approximately $14\frac{3}{4}$ miles, with a capacity of slightly over 76,000 gallons.

As the mains and service pipes when fully charged hold 76,000 gallons, it was decided that at least double this quantity of disinfecting fluid should be prepared in order to allow for leakage and other waste. The original intention was to leave about 240,000 gallons of water in the town reservoir and to add to this $11\frac{1}{4}$ tons of chloride of lime (33 per cent. of chlorine) in order to obtain a 0·350 per cent. of available chlorine in solution. Whilst this was being arranged, and experiments were being carried out to determine the action of chloride of lime on leather, lead, &c., one of us made arrangements—

1. To give an extra supply of water (prior to the commencement of actual operations) between the hours of two and six on Saturday afternoon, which might be stored from six o'clock on Saturday to nine o'clock on Monday morning, the period over which it was calculated the disinfecting operations would extend.

2. To shut off the outlet sluice of the reservoirs at six o'clock on Saturday evening and at once empty the mains throughout the whole system, which is shown on the plan.

It is to be noted that the drain on the reservoir after two o'clock on Saturday became so great that the sluice had to be shut down at 5.30, as only about 180,000 gallons then remained in the reservoir. It was necessary then to use only ten tons of lime.

3. To construct a weir around the outlet grating in the reservoir, so arranged that the surface, or clear supernatant, solution might be allowed to pass out as was necessary. A primitive but very effective apparatus was constructed round the outlet of the reservoir to prevent spent lime gaining access to the delivery main. This consisted of a wooden screen about 4 feet square by 6 feet deep, fitted across the angle in which the outlet was placed. In this screen sluice gates or shutters, each formed of a single 7 inch board, were fitted, a shutter being withdrawn as the head of solution diminished, then another shutter, and so on, until the whole of the supernatant fluid had passed out. All these shutters were entirely controlled from outside the reservoir.

We were informed by Mr. E. Shrapnell Smith that, provided our instructions were properly carried out, not more than 0·5 per cent. of the available chlorine would remain undissolved in the sludge, i.e. we should have 32·5 per cent. available chlorine in solution. $10 \times 0·325 = 3·25$ tons of available chlorine $= 50,960,000$ grains in a total volume of $(180,000 \times 70,000)$ grains; hence each 100 grains by volume contained 0·404 grain of available chlorine or 0·054 grain per 100 grains by volume in excess of what we had calculated.

4. To cut extra holes—eight in number—in the service

reservoir at different points in the arches forming the roof. This service reservoir, rectangular in shape, is 89 feet by 89 feet, and is covered with brick arches carried on piers 11½ feet high. It has a capacity of half a million gallons. The holes in the roof, 18 inches square, were a few yards apart and so arranged that the lime might be shot in at different parts of the reservoir, and a more equal distribution thus obtained.

5. To obtain a fire-engine for the purpose (*a*) of creating currents in the reservoir and thus helping in the mixing of the lime; (*b*) of sparging and disinfecting the roof and sides of the tank; (*c*) of pumping out as much as possible of the residual milk of lime.

In conjunction with the Corporation, notices were issued to every householder in the district intimating that in order that the mains in the high-pressure area might be disinfected the water supply would be suspended in certain streets, roads, &c. (of which a list was given), from Saturday, October 16, 1897, at 6 p.m., until the following Monday morning, and asking the householders to observe the following instructions:—"Water required for use between Saturday, October 16, at 6 p.m. and 9 a.m. Monday, October 18, should be drawn off before 6 p.m. on Saturday, after which every householder should see that all taps are properly closed. At or about 11 p.m. the mains will be charged up with chlorine solution, when taps may be turned on for a few seconds and then closed."

At the same time much work in connection with the reservoir, mains, &c., was being hastily pressed forward. Extra hydrants were fixed at the various termini, and at every point of vantage, so that the speedy and effective draining of the mains might be completed at a given time. At the service reservoir at Barming, 11½ tons of chloride of lime was being prepared by crushing and screening; it was then placed in bags under cover in order to be ready for use.

Everything being ready, and in accordance with the instructions previously issued, the pumping engines were stopped promptly at 5.30 p.m. on Saturday, the outlet valve of the reservoir being closed at the same time. At 6 o'clock ten tons of the prepared chloride of lime was distributed in the sacks at the holes in the roof of the tank, and was rapidly emptied into the water—a little over 180,000 gallons. For two hours sixteen men with long poles kept stirring the water in the reservoir so as to get a thorough mixing of the solution of lime. The large steam fire-engine was also used to help in carrying on the mixing process. At eight o'clock this mixing process was stopped and the lime was allowed to settle out.

As soon as the valve had been shut down a separate staff

was employed to drain off the mains in the entire area by means of wash-out valves and hydrants. This staff was distributed over the district, which was cut up into small sub-districts, sufficient hands being employed to accomplish the individual tasks with ease, the whole work being carried out under the supervision of reliable inspectors whose duty it was to see that the mains were thoroughly drained and all valves and hydrants properly adjusted in readiness to receive the chlorine solution at the appointed time. This had all been accomplished by 7.30 p.m. At 10 o'clock the upper layer of chlorine liquor was quite clear and the first board in the weir was withdrawn, the sluice valve was opened and the filling of the trunk main began.

Everything appeared to be progressing satisfactorily when at 10.30 a report was received that a stream of chlorine solution was flowing from a hydrant near Bower Place, the valve having given way or become jammed. The stopping of the resulting leak took nearly three-quarters of an hour, so that the filling of the branch mains could not commence until after 11 o'clock. This would not have been a serious matter had not a large number of householders, finding that no chlorine water came through their taps by 11 o'clock (the time appointed), left them open and gone to bed; as soon therefore as the disinfecting solution was thrown into the branch mains much of it escaped at the lower levels, and some of the higher streets and houses received none at all. This failure of the solution to reach its destination at the time stated in our notice was regrettable and unavoidable, but it rendered necessary a division of the whole high-pressure area into districts (Nos. 1, 2, 3 and 4, shown on plan). No attempt, indeed, was made to charge the whole district at the same time, a plan that might have been followed in order to save time had everything gone well. The open taps would have rendered this impossible—there would have been such a great escape at the lower levels.

Each district was now charged separately, and full pressure maintained for half an hour in each. District No. 1 was first charged through seven 3-inch sluice valves off a 12-inch main, and after being kept under constant pressure for half an hour the solution was locked in until the service was restored. District No. 2 was charged through three 3-inch valves off a 12-inch main from 12 to 12.30 midnight. District No. 3 was charged through one 6-inch sluice valve off a 12-inch main from 12.30 to 1 a.m. District No. 4 was charged through one 6-inch sluice valve off a 12-inch main from 1 to 1.30 a.m., and in each case the solution was locked in.

As already mentioned many householders had by this time retired, and did not smell the chlorine until the supply was re-

sumed. That the entire mains and services were charged was proved by examination of hydrants at various levels, and especially at the highest points of the town, where men were located to see that air escaped and that the chlorine solution came through. We were ultimately convinced from the reports received that the operation had been satisfactorily carried out, though about an hour and a half behind time.

We could now turn our attention to the service reservoir, where some tons of spent lime and a small quantity of clear solution, not required for our purpose, still remained and had to be got rid of. The remaining solution, by the aid of the steam fire-engine hose and branch pipes, was used to wash down the roof, walls and piers of the reservoir. Then by means of constant stirring, the lime was mixed with the fluid and a milk was formed which was pumped out from the reservoir and run to waste.

A large staff of men worked most willingly, and the walls and floors were thoroughly cleaned with squeegees and brooms, the whole of the lime being removed, and the reservoir got ready for the fresh water supply. This was a most tedious business, and by six o'clock in the morning, every one was wet, tired and hungry—in fact thoroughly worn out—eyes were running, and there was a good deal of bronchial wheezing.

At last, however, the work was completed, and 6 a.m. Sunday morning saw the engine at one of the stations pumping back, up through the 12-inch trunk main from the town, the chlorine solution with which it had previously been charged. As this came up it was pumped out by the fire-engine. At 8 a.m. this portion of the undertaking was also complete, and when we left for breakfast, the reservoir was being refilled with bright clear water free from anything but the merest trace of chlorine.

Attention has already been called to the fact that the mishap with the hydrant rendered the plan of dividing the whole area into districts essential to the success of the undertaking; and, in the light of after events, there can be no doubt that this mishap was the turning point as regards the success or failure of our operations. Had the plan of treating the entire area at once been adopted, there can be no doubt that the solution would never have reached the higher districts in consequence of the enormous drain there would have been on the trunk main from the numerous taps and w.c. fittings that were left open during the night in the lower parts of the system. The division into four districts reduced this loss to a fourth during any single period, and it was possible for a greater pressure to be concentrated in the smaller area.

Of course there was waste in each single district, but as

soon as that district was shut off, the pressure could immediately be thrown into another. The delay was naturally somewhat disappointing to those householders who were expecting the chlorine solution to appear at a stated time. In spite of this, however, most of those who were spoken to expressed themselves thoroughly satisfied with what they had seen and smelt, each in his own house. Nevertheless, as was expected, it was impossible to satisfy everybody in an undertaking of this kind, especially where so large an area was concerned, and inspectors were sent round with instructions to find out whether any of the consumers had really not received the chlorine solution. From some of the very high districts a few reports were received to the effect that no chlorine solution had been drawn through the fittings, or that the occupiers, for some reason or other, were not satisfied.

Each complaint was separately investigated. In most cases we were satisfied that the disinfection had been properly carried out, but as it was our special object to satisfy everybody, additional local disinfections were carried out, even in houses situated at a low level which were placed between others where the occupiers had satisfied themselves by drawing off the solution from their taps.

District No. 1.—No complaints.

District No. 2.—Complaints were received from Queen's Road that the chlorine solution had not been drawn from the fittings.

District No. 3.—Similar complaints from Hastings Road.

District No. 4.—Complaints from Boxley Road, Gladstone Road, and Sittingbourne Road.

In each of the districts from which complaints were received notice was given that the water supply in those streets would be suspended; the mains were first emptied, and then charged from the highest point with chlorine solution stored in water vans. The sluice valve was now opened, and the normal water pressure was brought to bear so as to force the solution contained in the main through the services and fittings of the various houses from which complaints had been received. In many cases the services had to be turned off, as the consumers declined to have a second supply.

From experiments, made before this disinfection was carried out, we were convinced that a 1 per cent. solution of chlorinated lime would have little or no effect upon the leather washers, valves, &c. But, as already noted, the reservoir was overdrawn, and the strength of the solution was consequently more than 1 per cent. We had not allowed ourselves very much latitude, and the result was that the stronger solution affected

the leather valves, inasmuch that nearly every tap in the area started leaking, and eventually had to be re-leathered.

The wearing apparel, boots, &c., of the workmen engaged were very much damaged, and later on we ourselves found that we had no further use for any of the articles worn on that occasion. Still it must be remembered that we were working continuously in chloride of lime solution for about fifteen hours. The fire-engine pump-buckets, and delivery and suction hose, which dealt with the solution, were entirely destroyed. Apart from this, however, there was not the slightest damage, or ill-effect of any kind, traceable to the use of the chlorinated lime solution.

As a result of our treatment, we were satisfied that, so far as the mains which conveyed the high-pressure water were concerned, there was no possibility that any typhoid organisms could continue to exist; and what was true of the mains was equally true of the service-pipes. In fact we were satisfied that no micro-organisms of any form that could have obtained access to these pipes from the high-pressure service could remain alive and active.

This part of the work being complete, our attention was turned to Section B—the rural district, which included the pumping station at Barming, the rising and distributing mains in the parishes of Barming and East Farleigh, and the reservoir of the Kent County Asylum at Barming. The lengths and capacity of the mains now to be treated were, approximately—

	1920	yards of	12-inch	main
	473	" "	6-inch	piping
	1326	" "	4 "	"
and	113	" "	3 "	"

a total of 3832 yards, or a little over two miles, with a total capacity of 32,000 gallons.

Here the method of procedure was almost identical with that previously described, with the advantage, however, that it was carried out during the day instead of at night.

The reservoir—covered in—is situated in the Asylum grounds at an elevation of 260 feet above Ordnance Datum, and has a capacity of 100,000 gallons. The water was run off until 50,000 gallons remained, and to this was added 3 tons of chloride of lime. The mixing process was carried on as in the first series of operations, after which the lime was allowed to precipitate for about five hours. Whilst this was going on the mains were all emptied and the valves closed. When the supernatant fluid was quite clear, it w s pumped by the fire-engine into the rising main, which delivered into the top of the reservoir. From this,

the highest point, it gravitated back to the pumping station and the distributing mains of East Farleigh and Barming parishes. The inspectors were sent round to visit all the houses in these districts, with instructions to draw a small quantity of the solution from each and every service-pipe. Previous to this being done a second quantity of a similar solution was prepared at the pumping station and run into the sump of the engine-room. When the mains were fully charged, the engine was started, and the solution was passed through the pumps and air vessel into the rising main. The solution which was then of no further use was run from the reservoir through the tanks and services in the Institution. The walls and roof of the reservoir having been previously sparged by means of a hose-pipe and nozzle from the fire-engine, the whole of the chlorine solution in the mains was run to waste and the mains were re-charged with clear water from the high-pressure service reservoir in section A. The Asylum reservoir was thoroughly cleansed and the operations were completed, having extended over a period of twenty-four hours.

We believe that this is the only instance in which disinfection of water mains has been carried out on anything like so large a scale, and, although the difficulties to be surmounted were by no means small, we were thoroughly satisfied with the results.

It was thought desirable to place on record our method of working in some detail, as we fully anticipate that similar operations will, from time to time, be necessary in connection with other outbreaks of typhoid, cholera, &c.

As soon as it was announced that chlorinated lime solution was to be used, we received advice and offers of assistance from a considerable number of manufacturers of various antiseptics, and without denying that certain of these might have been used, probably with success, we are satisfied that with no single substance with which we are at present acquainted, could we have felt equally certain that the disinfection could have been so thoroughly, quickly, and harmlessly carried out. The very fact that chlorine has an easily and well-recognised pungent odour was all in favour of the success of the undertaking.

DISCUSSION.

The PRESIDENT proposed that a cordial vote of thanks be given to the authors. Dr. Woodhead had written to say that, although he had arranged to be present, he was unfortunately obliged to be absent, owing to an important professional engagement in Edinburgh. There was no doubt that engineers of water companies were not anxious to have such troubles as Maidstone had had recently, and they hoped they would never have to deal with such a state of things as had been found in that town. But at the same time it was well for them to learn, so that, when troubles came before them, they might be prepared to deal with them. In this respect the present paper was very useful. The one thing in the paper which struck engineers, and especially those connected with water supply and sanitary works, was that the adoption of chloride of lime appeared to have had a very deleterious action, not only upon the clothes of the persons engaged in the cleansing and disinfection of the mains, but also upon the leather washers of the stop-cocks. That seemed to him to be the objection to the use of chloride of lime. But, on the other hand, it was said that the other disinfectants which had been suggested were not so certain in their action. If that was the case, there seemed to be a need for a disinfectant which would be as effective as chloride of lime and equally pungent in odour, but which would not damage the leather of the fittings of the water pipes.

The vote of thanks was carried by acclamation.

Mr. BERTRAM BLOUNT said that those present would be sorry for the unavoidable absence of Dr. Sims Woodhead. With regard to the subject of the paper, several points called for comment. One of these had been alluded to by the President, namely, the effect which chloride of lime produced upon the leather articles with which it came into contact. The corrosive action seemed to have extended to the garments of the operators. But still, such a drawback was not likely to check the use of what was, after all, an admirable disinfectant. Chloride of lime was an old friend, but it had been under a cloud, and had been put aside as hardly sufficiently modern to merit the attention of up-to-date people. It was therefore refreshing to learn that, when a difficult and dangerous task was set before a water engineer, he turned to his old friend and used it for sweeping away objectionable organisms, instead of employing something perhaps with a finer name, but not half as good.

Confronted with the problem of cleansing a long series of pipes, the engineer was in a difficult position. Clearly, if the pipes were to be cleansed in an absolute way, and all the materials composing the mains and fittings were quite incorrodible, and expense was not a matter to be considered, a variety of substances would be open to the engineer. If it was possible to induce the consumers to abstain from taking water for a long time, a number of other courses would be possible But the real conditions were complex. To begin with, the substance to be used as a disinfectant must not be so violent in its action as to attack the ordinary fittings to a serious extent. In the second place, the householders must, if possible, be unharmed. Under such complex conditions, the disinfectant which had been adopted appeared to him to be admirable. He was a little surprised that it was not made more active and effective by the simple process of acidifying the solution of chloride of lime. Most of those present knew that a solution of chloride of lime was not fully active when it was in a neutral or alkaline state. But when it was acidified, so as to produce hypochlorous acid, it was a great deal more active than a solution of chloride of lime only.

It was upon that fact that the efficacy of those various electrolysed solutions, such as solutions of magnesium chloride, prepared by the Hermite process and others, depended. Those processes had been considerably in vogue, and the efficacy of the solutions resulting from them had been explained by various untenable theories. The one great cause that gave efficacy to such electrolysed solutions was that they contained loosely combined hypochlorous acid, and the effect could be obtained by simply acidifying chloride of lime. But on reflection it appeared that perhaps it was the wiser plan, after all, not to acidify. One did not require the sterilising solution to be unduly active and to expend its activity before it had reached all parts of the system. So he thought that the suggestion, which at first appeared to him to be reasonable, might be dismissed.

Mr. John Shaw said that he was very pleased with the manner in which the authors had treated the subject. They had told them the whole truth concerning the treatment of the mains after the epidemic. His impression was that they had not only used the very best thing in disinfecting the mains, namely, chloride of lime, but that they had used it in the very best way. Mr. Blount had referred to the question of acidulating the chloride of lime solution, so as to throw the chlorine free, but his (the speaker's) experience had been that where

chloride of lime had been treated with acid, it gave off the chlorine gas before it was wanted. The disinfectant was wanted in the water mains, and the chlorine gas would have been given off before the solution reached the extent of the mains if the solution had been acidulated in the reservoir. Probably the greater part of the chlorine would have been given off in the reservoirs, and would not have acted upon the mains at all. On the other hand, if the solution were sent down the mains in a concentrated form, the whole of the chlorine would go into the mains and do the work.

He did not think that it was altogether an evil that the chlorine should have attacked the leather valves. As a general rule, where there was any animal matter the microbes would flourish and grow, and very probably it was a blessing in disguise that the chloride of lime should have acted on the leathers of the taps and the leather washers. It was probably the best thing that could have happened for the Maidstone Water Company, inasmuch as it would assure consumers that the mains had been thoroughly disinfected. There were other disinfectants that possibly might have been used, but they were very much more dangerous and more poisonous than chloride of lime. Carbolic acid was of a very much more poisonous nature, and it was very possible that it did not do its work so well as the simple old disinfectant, chloride of lime. Mercuric chloride was also very much more poisonous than either carbolic acid or chloride of lime. He should like to hear from Mr. Ware whether he had any difficulty in some of the outlying mains some days after the chloride of lime solution was used. In some cases the smell of the chloride of lime lingered about for a week after the solution had been used, and he had been wondering whether that had happened in this case, and whether any means such as the use of bisulphate of lime had been needed to counteract the smell in any part of the mains.

Mr. F. W. Alexander said that he had learned a good deal from the paper. But it had struck him that there was a good disinfectant which had not been mentioned, and that was formic aldehyde. It was used under the name of formalin, and it might be borne in mind by those requiring a disinfectant at some future time. A very small quantity of it went a very long way.

Mr. G. Maxwell Lawford said he understood that the liquid disinfectant was carried right into the very taps and fittings of the houses. Was not that the case?

Mr. Ware said that it was.

Mr. Lawford then asked whether the houses in Maidstone

had cisterns, and if so, whether the disinfecting water was carried into the cisterns in the houses? That point was not referred to, but it seemed to be an important one. If the disinfectant was left in the cisterns, it might be difficult to get it away from them subsequently. He also asked as to the condition of the mains. There was no reference made to that point in the paper. Were the mains in any way encrusted before the solution was put into them; and if so, had the solution any particular effect upon the incrustation? He asked these questions simply for information. He was himself carrying out a somewhat large scheme of water supply only a few miles from Maidstone, and he was taking the water from the same sources as the Maidstone water; but he had the advantage of the gault clay interposed between the lower greensand bed and the surface. Of course, the water had to come a very long way before it came to his supply. He also asked whether anything in the nature of sterilisation was attempted in the case of the Worthing mains after the very serious epidemic of typhoid there.

Mr. Arthur Rigg said that Mr. Shaw had said that microbes made their homes in leather or other animal matter required for packing the taps for household use. That might very likely be a correct idea, but if the taps were made in a better way or packed with fibre they would not need leather, for it was perfectly easy to make taps which could keep watertight without packings of leather. He had seen taps made of soft metal and not properly finished, and, in order to make amends for their intrinsic badness, leather washers had been put into them.

With regard to microbes, there was a vast number of them which people must "eat, drink, and be merry" with, or else they (the people) would never be able to exist at all. The only thing which occurred to him with regard to what might be a very useful addition to the paper was that the authors might add a short summary of what happened at Maidstone in regard to the typhoid epidemic before their arrangements were made, and what happened afterwards.

He did not know much about disinfectants; but he remembered that when he was learning chemistry there was only one disinfectant known, and that was chloride of lime. Now they were brought back to the same material. It was very curious to see the evolution which had taken place and the return to the old substance.

Mr. Perry F. Nursey said he quite agreed with Mr. Shaw

that the destruction of the leather was a blessing in disguise. It showed the inhabitants that the disinfectant had taken full effect; but he thought that the blessing went a little way beyond that, for the destruction of the leather insured absolutely that none of the microbes which might have found their way into that leather could possibly do any harm, for the leathers themselves had to be removed. If the leathers had not had to be removed some of the microbes might still have remained and have made themselves felt at a future time. The blessing was a double one in that respect.

Mr. W. E. Froome Crook asked Mr. Ware if he could give some particulars with regard to cases of typhoid both before and after the operation of disinfecting had been carried out. That would have some bearing as showing whether or not the disinfection was successful.

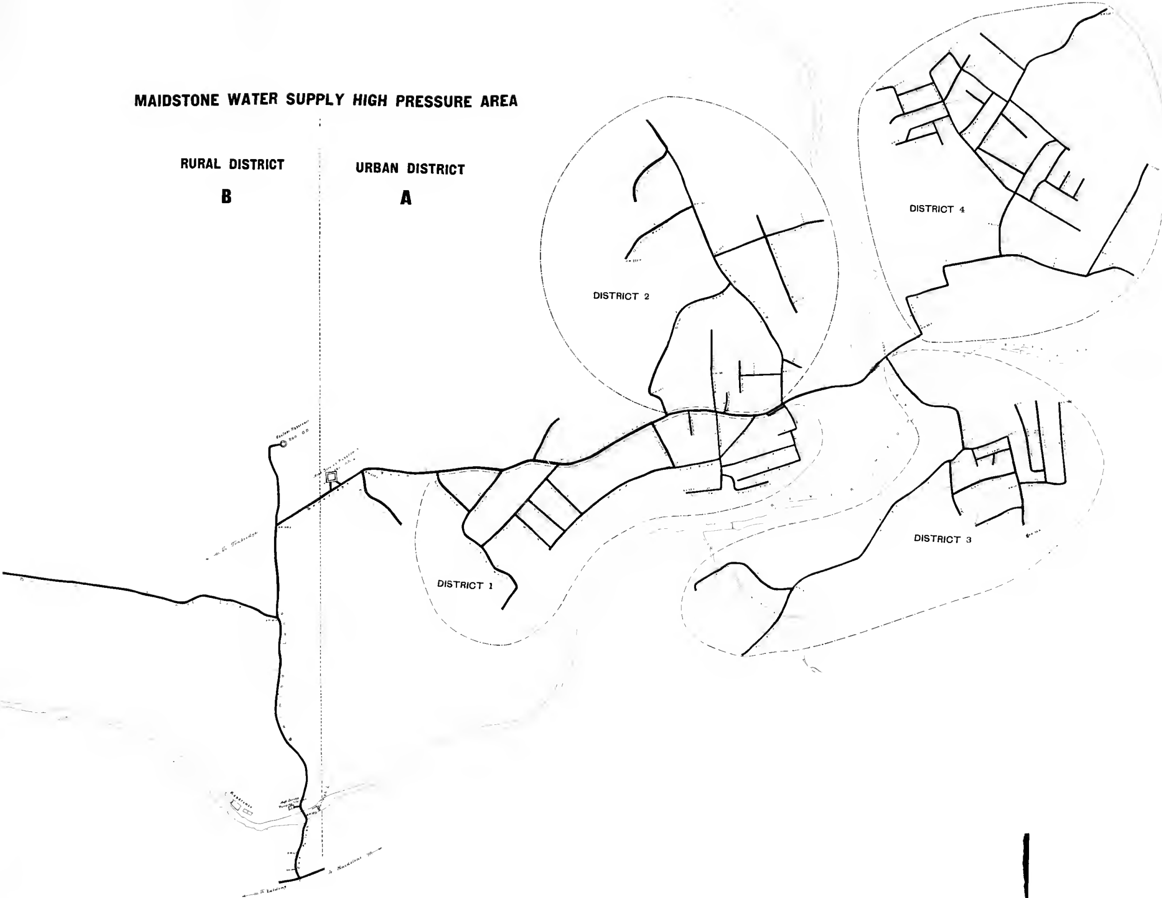
Mr. Ware, in replying upon the discussion, said that there seemed to be a difference of opinion as to which disinfectant was most effective or most useful, but that always happened with experts. Dr. Woodhead went very carefully into the matter, and he (Mr. Ware) did not think that there was anyone more capable of judging what was most suitable for the purpose than Dr. Woodhead. Mr. Shaw asked how long after the cleansing the acrid taste of the chlorine could be detected. The answer to that was that a little trouble was experienced for a day or two, but not longer; the longest time recorded was two days. In reply to Mr. Lawford, there were comparatively very few cisterns in Maidstone, as the water company gave a constant supply, and cisterns were therefore not required. But there were houses of the better class in which cisterns were in use. In those cases the cisterns were filled, or partially filled, with the solution according as to how much water space was available.

As to the condition of the mains, no difference had been noticed in the corrosion since the disinfection was carried out. Some of the mains had been down since 1860, and not the slightest sign of corrosion had been noticed. He did not think that the chloride of lime affected them in any way. He was sorry Dr. Woodhead was not present to reply to the question about Worthing, for he had had considerable experience with that town. He (the speaker) knew very little about Worthing.

As to the number of cases of typhoid before and after the sterilising of the mains as referred to by Mr. Rigg and Mr. Crook, he had not with him any facts or figures which would

enable him to go into the matter. There had, however, been a Local Government Board inquiry held, in the report of which all the statistics had been given. It should be borne in mind that the paper dealt with the sterilising of the mains only, and not in any way with the disease.

MAIDSTONE WATER SUPPLY HIGH PRESSURE AREA



May 7th, 1900.

HENRY O'CONNOR, PRESIDENT, IN THE CHAIR.

THE ECONOMICAL DISPOSAL OF TOWN REFUSE.

BY BRIERLEY DENHAM HEALEY.

OWING to the vast sums which continue to be expended upon plant for the disposal of town refuse, and which increase by leaps and bounds every year, the subject of this paper should now be of greater importance than at any previous period. The chief aim of the author is to explain the various systems adopted for burning this refuse, and of utilising the heated gases in such manner as to make the process truly economical.

It will be admitted that the first duty of all sanitary authorities is to collect and dispose of their refuse matter with as little inconvenience as possible to the residents of their own districts, and without causing any nuisance to them or to the residents of bordering districts. The work should be done as economically as circumstances will permit, always having due regard to efficiency, and it will generally be found that the greatest economy lies in having a thoroughness in everything. There is a great quantity of refuse, known as trade refuse and manufacturers' refuse, which the authorities object to deal with, and it is well known to experts that many manufacturing firms make as much combustible refuse as would supply sufficient steam for their works if properly burnt. But in many cases there is not space for an additional boiler and so the waste goes on, although in many such works the combustible matter is a source of danger if not removed daily.

Before deciding upon any system for using town or other refuse as fuel, especially when it is intended to obtain considerable power from the heated gases, a very careful estimate should be made of the fuel value of the refuse, by noting the average percentage of combustibles and water which it contains, and this can be done quite satisfactorily by taking several samples at short periods from different loads at each period. When considering the most important question of economy in working, with a view of fixing upon a system for any particular

place, an account should be taken not only of the capital outlay but also the guaranteed cost of working, and estimated value of the steam which each system will produce, as it is often found that an enlargement of the capital outlay ensures the best results in working.

In well-constructed furnaces which are worked with natural draught, the rate of consumption is from 20 to 30 lb. per square foot of grate surface, and when using forced draught it ranges from 30 to 60 lb. per square foot per hour. With an ordinary grate of 25 square feet, burning 25 lb. per foot per hour, the consumption per week of six days amounts to 40 tons. The weight of refuse varies from 28 to 87 lb. per cubic foot, or say, from 25 to 80 cubic feet per ton. The variations in the rate of consumption are so very considerable in different districts as to make it very difficult to obtain fair comparisons of the various systems in use. The lightest is not suitable for heavy draught furnaces, and has been found difficult to drop from barges at sea, but it may be dropped into furnaces by means of boxes with hinged bottoms, although the heavier sorts of refuse should always be fed down suitable slopes.

The carbonaceous matter in town refuse varies from 20 per cent. to 50 per cent., and has lowered very much in value during the past twenty years, more especially in towns and cities where gas fires are in extensive use. The moisture in town refuse varies from 15 per cent. to 47 per cent., organic and animal matter having 70 per cent. to 80 per cent. of moisture, and refuse mixed with sewage sludge has about 75 per cent. The clinker varies from 19 per cent. to 42 per cent. of the refuse charged, and it may be used for various purposes if care is taken in working the plant.

The aim of many authorities, for twenty years or so, has been to pass as much refuse as possible through the smallest number of furnaces, with the consequence, in many cases, of causing a nuisance by imperfect combustion, and where steam generators have been used the furnace gases have been forced through them at the greatest velocity, altogether regardless of efficiency or economy. It may be mentioned here that at least one well-built plant has done good service for many years, but the heated gases have all gone to waste, with the result that the splendid stack had to be bound with iron, at considerable cost, to prevent its collapse.

Capital Outlay and Working Expenses.

The average cost of plant, including the stack, flues, furnaces, suitable buildings, roadways, and usual machinery,

such as mortar-mills and clinker-crushers, with engine and boiler-power for driving the same, has been 850*l.* per furnace for a plant of eight furnaces. When, however, steam is to be obtained to the fullest extent by the addition of sufficient generators, the cost will then reach 1300*l.* per furnace, or say 65*l.* per I.H.P. obtainable.

The cost of working destructors varies from one shilling to three shillings per ton of refuse charged, exclusive of sinking fund, but inclusive of repairs and renewals. The great difference in these costs is due to varying circumstances connected with localities, as for instance, the class of refuse, rate of wages, the system adopted, the use made of the heat developed, and revenue from sale of clinker or mortar. It is, however, imperative that some recognised standard of compiling results should be established for future use, in order to avoid a repetition of costly experiments which are too well known to require mention in this paper.

The greater part of the data hitherto published on the disposal of town refuse by fire has been misleading, chiefly because some of the most important items in the results of every set of examples have been based upon circumstances which are always varying, so much so that it has been found impossible to name two towns where similar conditions could be relied upon for a fair comparison of different systems. Consequently many authorities have not at first obtained the plant which was the most suitable for their requirements.

In comparing the capital outlay efficiency, it is necessary to take into account the space occupied, the extent of structural works, roadways and pavements, as there is a marked difference between the compactness of the various systems for a plant of given power. This will be seen when considering the extent of a site for a system which has boilers between the furnaces, as against another with boilers away from the furnaces or set over the furnaces.

The heat developed by refuse as fuel varies considerably: a ton of Birmingham refuse yielding 200 I.H.P.; formerly Bury was only equal to 11 I.H.P. per ton; Rochdale gives 182, Cambridge 174, Hereford 149, Leeds 113, Bradford 82, Oldham 60, Hastings 40, Leyton 33, Southampton 16, Bath 12; and when due credit is given for the calorific value, in many places the actual cost of disposal is less than for the ancient systems of barging to sea, or dumping into disused quarries.

From the results of numerous experiments, confirmed also by returns of steady and continuous working, the following table of coefficients has been computed by the author, without regard to any particular system of combined apparatus, but

rather as indicative of results obtainable by various combinations of any thoroughly good apparatus. Column A gives the coefficients for steam generating only, B gives the coefficients for incinerating power of furnaces only, C gives the coefficients for the same class of boilers and furnaces in combination, and D gives the coefficients for the complete plant based upon the capital outlay.

Combination.	A	B	C	D
Two boilers per furnace	1·00	1·00	1·00	0·54
One boiler per furnace	0·91	0·85	0·88	0·81
Two furnaces per boiler	0·77	0·71	0·74	1·00

Although not the best steam producer, the last-named combination has the advantage when considering the capital outlay and actual working expenses, and has been adopted by a majority of the leading makers of destructor plant as the most convenient arrangement for general use.

To prove the calorific loss caused by connecting too many furnaces to one boiler, an experiment which was made with four furnaces produced 101·05 I.H.P., whilst six furnaces working to the same boiler produced only 100·00 I.H.P., and yet this error is practised every day. To emphasise this point another experiment in which twelve furnaces were connected to one boiler produced only 36 I.H.P., showing most conclusively that the draught was impeded, and the combustion and temperature were also proportionately lowered.

According to an official report which was issued September 27, 1899, in reference to the Darwen destructor, the calorific value of the refuse burnt there was 22¼ per cent. of that of coal which evaporates 7 lb. of water per pound; and from a report of the chief engineer of the St. Pancras Electricity Department, dated May 30, 1898, upon the water-tube boiler which was supplied by the Standard Furnace Company, under the supervision of the author, it appears that the actual capacity was 56·5 I.H.P. when using the gases from the furnaces, and was rated at 170 I.H.P. when fired with coal, so that 33 per cent. of the rated power was obtained when using refuse.

The number of destructors has been doubled during the past seven years, and up to the present date they have been adopted in 88 places. The total number of furnaces is 695, or an average of 7·9 at each place, and the total number of steam generators is 126, or an average of 1·43 at each place.

Assuming that the furnaces are all well constructed they are capable of supplying 222 additional steam generators, or, in other words, nearly two-thirds of the power is wasted. This waste amounts to 9000 I.H.P., taking 20 I.H.P. as the duty of each furnace, or at ·0635 of a penny per I.H.P., 17,328*l.*, which is the equivalent of coal at 4*s.* 2*d.* per ton when 1 lb. of the latter evaporates 7 lb. of water, but as a matter of fact, 40 I.H.P. per furnace is now regularly obtained.

Places Using Destructors.

The following list of towns and cities which have adopted one or other of the various systems which are mentioned herein, may be interesting as showing how world-wide this important question has become:—Ashton-under-Lyne, Bath, Batley, Battersea, Belfast, Berlin, Birkenhead, Birmingham, Blaby, Blackburn, Blackpool, Bolton, Bournemouth, Bradford, Brighton, Bristol, Brussels, Burnley, Burton-on-Trent, Bury, Buxton, Calcutta, Cambridge, Cheltenham, Darwen, Derby, Dewsbury, Dublin, Durban, Ealing, Eastbourne, East London, Edinburgh, Glasgow, Govan, Grays, Hamburg, Hampstead, Handsworth, Hanley, Hartlepool, Heckmondwike, Hereford, Hornsey, Huddersfield, Hull, Hunstanton, Hyde, Karachi, Kensington, Leeds, Leicester, Leyton, Liverpool, Llandudno, London, Longton, Loughborough, Madras, Madrid, Manchester, Nelson, Newcastle-on-Tyne, Norwich, Nottingham, New York, Oldham, Poplar, Plymouth, Preston, Rochdale, Royton, St. Anne's-on-Sea, St. Luke's, St. Pancras, Salford, Southampton, Sheffield, Torquay, Shoreditch, Teddington, Wallasey, Walker-on-Tyne, Wandsworth, Warrington, Whitechapel, Winchester, Woolwich.

Systems Generally Adopted.

The destructors hitherto used may be divided into three classes:—(1) Those which are only intended to burn the refuse as a sanitary measure, without any attempt to utilise the heat, and from which the clinker is mostly shot into old pits or quarries. (2) Those which have machinery for dealing with a large portion of the clinker, and for which some of the otherwise waste heat is used for generating the steam necessary for driving the same. (3) Those in which every effort is made to fully utilise the effluent gases of the furnaces, and to produce a vitreous clinker which is suitable for many useful purposes.

The arrangements for charging the furnaces are of three distinct types: (1) Hand firing of steam generator furnaces, or destructor furnaces which have level grates, a proceeding

which is not more laborious than top feeding, if proper arrangements are made for stowing the refuse as regards suitability of level and distance from the firing doors. (2) Feeding through hoppers above the furnace hearths or from back doors, and raking on to the fire-grates after each operation of clinkering, at suitable intervals to ensure good combustion. (3) Charging from hoppers above the back end of furnaces, by mechanical bars or plates, or by means of tanks with automatic shutters, all of which require the assistance of forks and rakes.

The various methods of clinkering are also very diverse: (1) Drawing the clinker on to the floor and quenching it with water, and after this waste of labour and heat, it is put into barrows and wheeled away. (2) The clinker, which has been previously drawn forward in the furnace, is loaded into wagons or barrows, and taken to the despatch floor to be sold or used. (3) The use of extremely wide dead-plates as introduced by the author, on to which reciprocating fire-bars deliver the clinker at a very low temperature, and from which it is withdrawn at regular intervals.

Some modern furnaces have been found quite suitable for the refuse of the particular place which the inventor had charge of, and no less than 16 tons of screened refuse was burnt to very hard clinker in twenty-four hours, week in and week out, but precisely the same arrangement was a complete fiasco at another place because the material was so entirely different, and in the latter case the heat was not sufficient to obtain vitreous clinker, and the furnaces were dismantled. The present-day improvements of destructors, both as regards the furnaces, steam generators, and ensemblement, are so much superior to those of ten to twenty years ago, that several of the older type have been considerably improved and others have been entirely rebuilt, chiefly in response to the complaints of the residents living in proximity thereto, the law costs in one or two cases having exceeded the cost of the necessary improvements.

Residuum.

The combustible matter should be so completely incinerated in the furnaces as to produce a good vitreous clinker, and the resulting effluent gases should be utilised in the most suitable type of steam generators. The clinker may all be used and a good profit will be made, with a complete plant for making pavement flags, ballast for concrete, paving gravel, and mortar. The following table shows the suitability of vitreous clinker for concrete. The briquettes were tested three months after they were moulded, the material was passed through a sieve having

sixty-four meshes per square inch, and the cement was of the best quality.

	B.W. in lb. per sq. in.
A. 3 parts clinker and 1 part Portland cement	214·0
B. 3 parts special sand and 1 part Portland cement	179·5
C. 3 parts flue dust and 1 part Portland cement	166·5
D. 3 parts pit sand and 1 part Portland cement	157·0

As forced draught is now commonly used in the various types of destructor-furnaces, it is only reasonable to assume that they can all produce good vitreous clinker, and therefore the value of the solid residue has not been taken into account in comparing the costs of working. Whether the residuum is used or not is a matter for the interested authorities to decide upon; but it may be mentioned that if it was fully utilised 90,000*l.* per annum could be saved from existing works by making pavement flags, or 40,000*l.* if the clinker was only used for concrete and gravel. If the clinker is to be used for good work it should be kept quite free from unburnt matter, and therefore any design of furnace is objectionable which does not provide separate openings for charging the refuse and withdrawing the clinker, as when the same doorway is used for both these operations it is impossible to prevent the mixing of small quantities of unburnt refuse with the clinker; and the same objection applies to grates which slope too quickly, although they may have a separate means of charging.

From the flues of furnaces which are worked at high temperatures, the flue dust is now a very valuable by-product. When mixed with ten per cent. of carbolic acid it makes a reliable disinfecting powder, at less than half the usual cost, and it has also been used for making silicate paint.

A most prolific source of complaint from residents generally living within a short distance of destructors, is the fine dust particles which settle down upon every ledge and window sill, and this nuisance is aggravated by very tall stacks when using natural draught only; with forced blast and shorter stacks, and the use of dust pockets in the flues, this nuisance may be entirely prevented. The furnaces which were built during the decade 1876 to 1886, were mostly of the Fryer type, of which a very great number were used. The grates and back hearth inclined at an angle of 20 degrees, and the feeding hole and down-flue were beside each other at the upper end of the hearth. This arrangement of outlet flue allowed a considerable volume of the gases of distillation and fine dust particles to escape into the flues along with the gases of combustion, and this nuisance generally was loudly complained of.

So great were the complaints made by residents living near

the destructors at Bradford in 1885, that the author was engaged to carry out certain experiments which were suggested by Professor Oddling, and the results then arrived at proved the necessity of passing the gases of distillation over the hottest part of the furnaces into front outlets, and of providing longer flues between the chimney and the furnaces with traps for the dust.

Patent Specifications.

The following extracts from patent specifications indicate how matters stood at that date, and how close was the contest for fume cremators.

Pickard, No. 1020, March 9, 1880, page 2, lines 33-41. "I have found that in the working of furnaces such as are at present in use for the burning and deodorising of refuse, the combustion and destruction of the gases and vapours which are distilled off the refuse are not in all cases complete. In order to ensure the perfect combustion and consequent complete destruction of such gases. if any should escape from my furnace, I place one or more additional or purifying fires in the flue between the chamber where the flue dust is deposited and the chimney, and I find that by this arrangement the products of distillation, in passing over these additional or purifying fires, are completely burned and destroyed, and that the gases and vapours pass out at the top of the chimney perfectly deodorised."

Healey, No. 7703, June 25, 1885, page 4, lines 12-18. "If the refuse is very inferior, and contains an excessive amount of moisture, I pass the fumes from drying chamber through a special coke fire, built with closed fire-grate and with or without steam-jet apparatus. One such coke fire may take the fumes from two or four furnaces, and may be in the same range as the main furnaces and may be built as one of them in all respects, or it may be built at a different level and in a separate place, as the nature of the application may require."

Jones, No. 8690, July 18, 1885, page 1, lines 4, 5, and 13-16. "Furnaces known as refuse destructors are now largely used for treating town-refuse, and the products of combustion often contain noxious gases or fumes. My invention consists in conducting the offensive and other gases and substances, the products of burning town refuse, direct into a fire and under the concave side of an additional furnace fire-arch constructed over the fire, and in the midst and through the intense heat of a furnace kept at high temperature."

It is very well known that the working of such coke fires, cremators, or additional furnaces, added far too much to the cost of disposal, in fact some of them amounted to as much as 50*l.* per

grate per annum, and whilst a few are still worked at irregular intervals, many have been discarded. It is also recorded that at one place complaints were made when the cremator was working, and when not at work no complaints were made.

Grouping of Furnaces.

Generally a single rank arrangement of furnaces is the most convenient and economical to work, and when more than eight furnaces are built there should be separate ways for carts inwards and outwards. If two ranks of furnaces are built parallel to each other, they should be charged from a central platform, whether the feeding is by hand or by means of automatic boxes. The clinkering doors of two ranks of furnaces should not face each other, but be quite apart in separate pits or caves.

For many years after the introduction of destructors the approach roadways to the charging platforms were inclined at about 1 in 16, and the clinkering floor was nearly level with an adjoining street. The author has built some hundreds of fuel furnaces below the ground level, which had inclined ways from the clinkering pits, and in 1880 he proposed the same arrangement for destructors. As there is only about one ton of clinker from four tons of refuse, it is certainly less costly to raise the clinker from pits than to deliver the refuse to an elevated platform. The first cost of the 1880 method is not nearly so great as the other, the structure is much stronger, and the buildings do not stand so high above ground.

For the removal of the clinkers, iron barrows or wagons, running upon plated tracks, are better than tramways. The dead-plates of all furnaces should be of extreme width to allow one lot of clinker to lodge thereon until the following cleaning of the grates. The distance from the furnaces to the chimney should not be less than the height of the chimney, and air spaces should be formed between the inner and outer walls. The greatest height of structure from clinkering-floor to charging platform need not exceed 14 feet, although some systems require much more as at present erected, and in other cases where the particular systems used do not require it, the height is as much as 18 feet. The length of the approach roadway or the way from the clinker-pit is in direct proportion to the height of the structure, and a saving in height means a reduced capital outlay.

In a great many instances where the levels of the sites have been favourable, destructors have been built without the inclined approaches which at one time were considered inseparable,

and in a few places electric, steam, or hydraulic lifts have been used for raising the refuse, and in connection with lifts it becomes easy to mix different loads of refuse as they are shot into the tanks, trucks, or boxes.

Main Flues.

A large area of flue and a slow velocity of current is required to allow the dust particles to be precipitated, but against this there is loss by radiation from increased surfaces of outer work, and therefore a mean has to be arrived at, especially when the heated gases are to be utilised. A minimum area of 24 square feet may be adopted with safety for a plant of not more than twelve furnaces, to which add 2 square feet for each additional furnace, whether using natural draught or forced blast.

Some years ago, when the author was connected with the Standard Furnace Company, he designed several plants, which were approved by the Local Government Board, in which the main flues were duplicated so as to allow of cleaning them without stoppage of the furnaces or boilers, and provision was made for shutting off any boiler or furnace without detriment to the remainder. With natural draught of the power usually adopted, a considerable volume of cold air is drawn into the flues through cracks in the walls and by filtration through the brickwork, and also every time the furnace doors are opened, even when flue dampers are connected thereto to act as throttles, so that there is a limit which economical working has settled in regard to both the power of the draught and sectional area of the flues.

After leaving the furnaces the gases pass over a series of dust traps, the simplest form of which is built across the main flues and has air-tight hinged covers. The covers are set open against the current when at work, and they are closed when the trap is full, and the dust is withdrawn by long scoops through side-entrance doors without admitting cold air to the flues. When using natural draught the temperature of the flue gases is considerably less than when using forced draught, the latter requiring about 2 lb. of air per pound of refuse burnt, or say 485 cubic feet per minute, for a consumption of 10 cwt. per hour, whereas double this volume of air is usual for natural draught, hence the lowering of temperature in the flues. It may here be noted that the volume is doubled by an increment in temperature of 485° F., so that whether using forced or natural draught the same size of flues is necessary.

Flue dampers consisting of steel plates made to work easily in slots which are formed in the brickwork have been proved the

most reliable, and when properly balanced, they are greatly superior to pivoted dampers for high temperatures. A well-made plug and sight-hole near each flue damper is necessary for taking the temperature and gauging the draught. A greater number of flue entrances than usual renders the process of cleaning less laborious, and a distance of thirty feet apart should not be exceeded.

Natural Draught.

Most of the earliest type of destructors had very tall stacks, upon which the designers relied for a strong natural draught necessary for the furnaces, as well as to disperse the generally obnoxious fumes which for a long time were such a serious nuisance. The tallest stack in use is 300 feet high, but there is an important public institution within half a mile of this stack, and at an altitude of about 200 feet above the top, so there is more than one reason here, as in a few other places, for extra height. Excepting the stack now mentioned, 52 per cent. of the remaining stacks are 180 feet high, 13 per cent. are 160 feet, 18 per cent. are 150 feet, 12 per cent. are 120 feet, and 5 per cent. are 105 feet, the average height being 158 feet.

When working with natural draught alone, the flue area of the stack should not be less than 20 square feet for the smallest installation, this size being sufficient for a plant of 12 furnaces. To this area may be added six square feet for every four furnaces beyond the first-named twelve, and the height need not exceed 150 feet above the furnace grates, unless the site is low compared with the district which the destructor has to serve. When using forced draught, the minimum flue area of the stack should also be 20 square feet, but in this case it will be sufficient for eighteen furnaces, and only one square foot need be added for each additional furnace. A height of 120 feet will exceed the requirements of the furnaces, which at the furnace doors should register ·25 inch water gauge, as the undergrate pressure of blast performs the chief duty of the hitherto extremely tall stacks.

In practice it has been found that forced draught furnaces work very well with stacks 60 feet high, and the greatest possible quantity of refuse can be properly incinerated in the furnaces with forced blast and such dwarf stacks. Nevertheless as even the purest gases from the most efficient furnaces are still unwelcome in a residential district, it will be far better to continue the idea of dispersion of the gases for some time to come.

Forced Draught.

The pressure required for efficient working with forced draught varies according to the thickness and the density of the material on the grates, but it should not at any time exceed 1·25 inch water gauge, and the flue dampers should be so regulated as to obtain not more than ·25 inch induced draught at the furnace doors, and these are the limits of pressure and draught for good working. To use a greater pressure more work is thrown on the stokers, as the fires burn hollow and blow into holes, which if not attended to allows the blast to escape, and not only reduces the pressure and rate of work, but the temperature in the flues also.

Rotary blowers of the very best make should be fixed in large open places as free from dust as possible, the inlets drawing the supply either direct from the outer air or through very capacious trunks, and driven by encased engines or electric motors. The air conduits to the furnaces should be quite four times the combined area of the blast inlets in ashpits, and the exhaust steam of the engines should be mixed with the blast by means of annular nozzles, by which system the grates will be as durable as when steam-jets are used, and a similar chemical action will take place in the incandescent part of the fires.

To settle the comparative efficiency of rotary *versus* steam-jet blowers, the author made some experiments in 1893 with a furnace of the standard type, having 25 square feet of grate surface. In each experiment the furnace was got to full heat before commencing to record the results, and every care was taken to ensure precisely similar conditions for each test. The steam pipes were well covered with hair felt, the steam pressure was kept at 80 lb. during each trial, and the blast mains and blower outlets were all 9 inches in diameter, which is the minimum for 25-feet grates.

The first experiment was with a Korting steam-jet blower, the initial nozzle being ·25 inch diameter, which gave a pressure of ·20 inch water gauge. The second experiment was with a small high-speed engine geared direct to a Sturtevant rotary blower, and by using exactly the same weight of steam the pressure was increased to ·60 inch. In these two experiments the furnace gases passed through a multitubular boiler 10 feet long and 6 feet diameter to a stack which was 40 feet high above the grate. Two other experiments were afterwards made without the boiler, and the furnace gases passed direct to a special chimney only 12 feet high over the furnace, and it was found that with the same blast pressure the incinerating

power of the furnace was as nearly as possible the same as before, which indicated the extra duty the stack has to perform when steam generators are used.

A fifth experiment was made with four Korting steam-jet blowers of the same size as the one used in the first experiment. These were fixed to a sole-plate at the top of the chimney 12 feet above the furnace and used as exhausters. The ashpit doors being open, it was found that the in-draught at the furnace doors was only ·25 inch water gauge. The power of the furnace was considerably less than in the other experiments, although using four times the quantity of steam. The result was anticipated, but the experiment was made to convince certain parties of the folly of using steam-jets to any large extent in chimneys.

Boilers and Results.

Destructor boilers have been set in many different ways, a large number of the small multitubular type having been set over the fires, without any intervening arch, and consequently the combustion was not quite perfect. Other boilers of larger capacity have been set alongside the main flue not far from the destructor, but in almost every case the flue area about the boilers has been very contracted, and the heated gases could not be fully utilised.

Radiation should be prevented as far as possible by building all the exterior work with a space between the inner and outer walls, a system which the author has used for nearly thirty years with great success, and which has been adopted by several engineers in plants of recent date. Experiments made by the author over twenty years ago proved that where it was impossible to obtain a temperature of 1200° F. with solid walls, a temperature of 2000° was easily maintained when spaces were formed in all the outer walls and coverings.

It is most important that every boiler which is fired with fuel of any kind, should have a good chimney damper, and that the practice of regulating the steam supply by the opening of furnace doors or closing of ashpit doors, should not be resorted to when the use of the damper would have the same effect, as the boilers often suffer more from the want of dampers than from performing their actual work.

Generally the steam generators which were used for many years after the introduction of destructors, were unavoidably of the multitubular type, the heated gases passing through the tubes and surrounding flues. The maximum steam pressure

was for a long time only 80 lb. per square inch, and it was very seldom that any more than 60 I.H.P. was utilised from the largest installation.

Lancashire boilers are now used with very fair results, and under the Meldrum system a pressure of 120 lb. can be easily maintained. The additional element in details which has led to the extended use of these boilers, is the recuperator by means of which hot air is obtained after gases have passed the boiler, and it is drawn to the ashpits by steam-jets of the Meldrum type.

Within the last few years water-tube boilers have become more common, and they are no doubt the most suitable type if properly set, and when arrangements are made for catching the mud in the water and steam drum, so that the steam generating tubes may be kept perfectly clean. To back up this theory the Standard Furnace Company supplied a boiler with such improvements for the St. Pancras plant 3½ years ago, which has worked continually ever since. The mud from the upper drum when dried and weighed averages 30 lb. per month (Fig. 11).

The thermal storage system, as designed for Shoreditch, in connection with water-tube boilers for a maximum pressure of 400 lb. per square inch, necessitated a very heavy initial outlay, altogether out of proportion to any possible advantages, as all the pipes, valves, and fittings had to be strong enough for the full pressure, and extra covering was also necessary on all steam charged vessels and hot feed pipes to provide for increased temperature. The temperature of steam at 120 lb. pressure being 341° F., and at 400 lb. pressure 444° F., the gases leaving the boilers carry away a very high thermal value, and although an economiser may be used for utilising some part of it, most excellent results are obtained at other places without economisers, and it now appears that Shoreditch works very well at a pressure of 150 lb.

Taking an average of several systems, it is found that 1·26 lb. of water can be vaporised by 1 lb. of average unscreened refuse, when burnt in well-constructed furnaces, and assisted by a forced draught at a pressure of 1·25 inch water gauge. By the use of screened refuse, 1·89 lb. of water can be vaporised per lb., but as it requires at least three tons of unscreened to produce two tons of screened refuse, there is no advantage in adopting screens, but on the contrary there is a loss of labour, as well as increased first cost and value of the extra space occupied.

Fire-Grates.

Several systems of moving fire-bars have been used for nearly twenty years, the primary object being to break up the clinker, and open the air spaces, and thus permit of a more regular and perfect combustion of the fuel than is possible by any arrangement of firing where fixed bars are used. In the year 1881 the Galley rocking-bars were introduced, but the teeth were too short for destructors; then came the Stevenson and the Settle rocking-bars, which had longer teeth, and also the duplex rocking-bars, which were introduced by the author in the year 1887. Of the first-named systems of bars, three were rocked from or near the centre of the webs, and they moved in one direction at the will of the operator, but the duplex motion bars were geared so that the even number bars moved backward when the odd number bars moved forward, and the clinker was lifted and broken up (Fig. 1). All these different designs of bars were laid across the furnaces, and connected by link bars to a simple knuckle attachment under the dead-plate, which was operated by a movable lever.

Forwarding bars, which run from back to front of grates, and are operated by eccentrics or cams at one end only, are capable of feeding the furnace, and at the same time delivering the clinker, and by the use of such mechanical arrangements, where properly set up and attended to, the labour of working destructor furnaces is reduced very considerably, and the steam raising capacity of the plant is greatly improved (Figs. 2 and 3). The author has given special attention to this method of stoking for several years, and the only drawback against its use was the necessity of lubricating the cam shafts, which, by the use of forced blast improperly applied, wore out with twelve months' work. When forced blast is used in connection with such bars, the wall boxes and bearings should have a supply direct from the mains, so as to prevent fine dust being blown into them, in other words an equilibrium of pressure should be set up in the gearing boxes.

Generally the air spaces between the fire-bars of forced-blast furnaces need not exceed one-fourth of an inch, and the spaces between the bars of natural draught furnaces should not be more than three-eighths of an inch, because an excess of width permits a large proportion of small combustible matter to pass to the ashpits unburnt. The same remarks apply with equal force to fire-grates which are used for burning coal-slack or coke, yet it is well known that many extensive users of steam, including some large engineering firms, have grates with air spaces nearly an inch in width.

Regularity of Operations.

In the firing of any kind of furnace, whether by hand or by mechanical means, it is of the greatest importance to observe a regular cycle of operations, so that there shall be a continuity of work and uniformity of temperature, not otherwise obtainable but at all times possible, and which is the best way of ensuring the greatest efficiency of any plant, both as regards the quantity of refuse burnt, the thermal value of the effluent gases, and the vitreous character of the clinker.

When the workmen are left to their own devices, it generally means that all the furnaces are clinkered as rapidly as possible, charged up or levelled down with corresponding expedition, and then there is an interval for what appears to be well-deserved rest; but during the earlier part of that interval the furnaces may be sending forth volumes of unburnt gases, and the temperature will suddenly fall as much as 700° F., simply because all the work is allowed to be done in an intermittent manner, instead of making the work extend over a period which equals the time of a full cycle.

Modern Furnaces.

During the past seven years very considerable improvements have been made to the Fryer type of furnaces by Messrs. Boulnois, Wood and Brodie (Fig. 4), including charging apparatus, movable fire-bars, and setting boilers. The charging apparatus consists of a tank with several compartments, and is constructed to run upon rails over the furnaces, and provided with automatic gearing for opening and closing the furnace charging-hole. Each compartment contains sufficient refuse for a charge, and any part of the tank can be readily put into position, either to receive the refuse from the vans or to charge it into the furnace.

A water-tube boiler is set between each pair of furnaces, and the effluent gases of the furnaces enter the boiler chamber through side outlets near the front, and after passing between the boiler-tubes in the usual way they escape to the chimney flue. A fire-grate is provided for each boiler, which may be used either as a cremator or to help in generating steam when refuse is scarce or when the demand for steam is suddenly increased. This arrangement of boiler-setting takes up more space and exposes a greater surface for radiation from one unit of plant than an overhead system of boilers. The fire-bars are of peculiar form, the upper end having a quick curve, and

alternate bars are rocked at intervals by means of toggle-gear and a cataract arrangement, which feeds the charge forward and at the same time opens the air spaces. The combustion is assisted by forced draught obtained from rotary blowers of the Sturtevant type, and altogether very satisfactory results have been obtained, both as regards the quantity of refuse burnt and the steam produced.

A great many authorities have adopted the Horsfall furnace, the gases from which have never caused any serious nuisance, and for which no form of cremator has ever been required to deal with them. The outlet flues are in the roof near to the front and the effluent gases pass over the furnace crown, and then through down-flues to the main flue which leads to the boiler and chimney. The improvements made by Mr. George Watson allow of the charging holes being arranged centrally, so that each charge can be pushed fairly down the slope without much side work in spreading the same. For a plant of, say, four to eight furnaces, a steam generator is set alongside the main flue not far from the last furnace, and up to this point the flues are generally at a red heat, but so far the generating power has not been fully used. Cast-iron boxes are built in the side walls of the furnace above the fire-grate, through which the air blast is led to the underside of the grate, and the cooling effect of the air prevents the clinker adhering, as it generally does, to the sides of brick-lined furnaces, and makes the clinkering far less laborious.

A special design of steam-jet apparatus is used for forcing the draught, which is conveyed in very large flues to the furnaces, but the use of these flues was known before the date of Mr. Watson's patent, and he has been good enough to inform the author that his claim is narrowed down to the combination of the air ducts. Generally this furnace has a broad likeness at first sight to the design which was patented by the author some years prior to that date, and there is no reason why both designs should not give equally good results (Figs. 5 and 6).

The Warner furnace has been adopted to a very large extent, and is now combined with steam generating (Fig. 7). It has an inclined grate and back hearth, and over the latter are charging hoppers which are fitted with falling flaps, so as to drop the charge upon the hearth. The flue outlets to the boiler are at the sides, and when the heat is not required for the boiler, the effluent gases pass off through an outlet at the back end of the furnace. By the use of forced draught from rotary blowers the combustion of the refuse is rapid and perfect, and there is a simplicity in the working of this apparatus which

is commendable. One boiler and two furnaces form one unit of plant, and below the boiler there is a good dust pocket. Rocking bars are used for the fire-grates of the type indicated by Fig. 1, and the complete apparatus is thoroughly reliable.

The Beaman and Deas furnace is very similar in its general outline to the furnace introduced by the author in conjunction with water-tube boilers in 1880, which were set between the furnaces for the first time as a combined apparatus (Figs. 8 and 9). The method of feeding the refuse is more laborious than for any other system at present in use, partly in consequence of the furnace doors being at the sides, whereas for all other systems the designers have put the doors at the front. Forced draught is obtained from rotary blowers, and the combustion of the gases is completed at a very high temperature, and the latter is taken advantage of for generating steam in water-tube boilers. The boilers are set on the same level as the furnaces, but on the opposite side of the main flue, and the outlet end of the boilers rests over the chimney flue. This class of plant is not as compact as some of the others, and the loss of heat by radiation and absorption is unavoidably greater.

The Meldrum recuperative furnace is associated with hand-firing and Lancashire boilers, but remarkable results have been obtained, and it must now rank as a destructor (Fig. 10). The furnace gases from four grates pass into one combustion chamber, and the latter also traps the greater part of the fine dust. Thence the gases pass into the tubes and through the flues of a Lancashire boiler, and on emerging from the boiler they are further utilised for heating the incoming air for the furnace. Steam-jet blowers are used for the forced draught, and there is the unavoidable noise which even the late Sir William Siemens failed to suppress. From the results of independent experiments already named, this system of drawing hot air from the recuperator must be a great waster of steam. The combustion of the gases is perfect, and the labour of charging is not greater than usual. In front of the furnace, at a convenient distance and level, is a deep hopper for the daily supply of refuse, and there is no nuisance from this system of storage.

The furnace, which was designed by the author in 1896 (Fig. 11), is constructed by the Standard Furnace Company, and has the main flue above it, so that the effluent gases can be passed to any of the boilers which are set over it, and any boiler or furnace can be shut off without interfering with the remainder. Any kind of fire-grates may be used, although the author has a preference for mechanical ones, and if properly fitted up, they are undoubtedly the most suitable.

In adopting water-tube boilers as at present working at St. Pancras, the author makes the width of the setting much

greater and the height proportionately less than for solid fuel firing. There is only one bridge over which the gases have to pass to the chimney outlet, and this ensures the lowest velocity of current whilst giving the maximum flue area. Under this system the loss by radiation is absolutely irreducible, and a maximum efficiency is always obtainable, as the generating tubes are kept constantly clean.

A most serviceable steam generator for combination with any type of furnace, or, better still, for setting between two common flues, is built up with vertical tubes and top and bottom headers, whilst the latter are connected to opposite ends of an upper drum (Fig. 12). The author's arrangement for drawing off all sediment from the overhead drum will perform the most valuable duty in this modification by keeping the generating tubes clean inside, but in addition they have to be kept clean on the outside, and by the use of scrapers this can be done more effectually than by any other means.

This paper would not be complete without a reference to the work of Pickard, Richmond, Pease, Lupton, Kidd, and Whiley, each of whom has made some discovery in the adaptation of general principles which has since been perfected and adopted by later inventors with more or less success.

At the end of the paper will be found a Table of results showing the comparative efficiency of working of the modern systems referred to by the author. He suggests the following method of standardising the results of official and other trials. Its object is to enable fair and reliable comparisons of different systems to be made. The various results should be arranged in accordance with the tabulated statement just referred to. In recording temperatures they should be taken hourly for a whole day and then averaged. Injectors should be used for feed water supplied from measuring tanks. Wages to be rated uniformly at sixpence per hour per man. Duration of trial not less than one full week, day and night. The annual amount of sinking fund required to pay off the capital cost and royalties in twenty years, allowing for 3 per cent. interest, should form an item in the table of results. The unit of plant operated upon should be as nearly as possible of the capacity shown in the Table of results.

The author uses the following formula for calculating the efficiency of capital and revenue accounts referred to at X as capital outlay, in Table of results.

C = Sinking fund for plant of given capacity.
W = Net cost of destruction per annum.
R = Tons of refuse incinerated per annum.
S = I.H.P. per hour of steam generated.
X = Coefficient for comparing various systems.

TABLE OF RESULTS.

—	—	1	2	3	4	5	6
A	Type or system of plant	Meldrum Brothers	Horsfall Fur. Co.	Standard Fur. Co.	Wood and Brodie	Warner's Perfectus	Beaman and Deas
B	Number of furnaces or grates	4	4	4	4	4	4
C	Grate area in use in square feet	104	100	108	108	100	100
D	Number and type of boilers	1 Lanc.	1 tubular	2 W. tube	2 W. tube	2 tubular	2 W. tube
E	Heating surface in square feet	915	1830	2236	2000	1620	1940
F	Tons of refuse burnt per diem	31·99	31·84	40·66	33·50	32·00	64·06
G	Burnt per foot of grate per hour	28·8 lb.	29·8 lb.	35·1 lb.	28·9 lb.	29·9 lb.	59·8 lb.
H	Steam pressure in lb. per square inch	180	128	120	150	81	105
I	I.H.P. of steam per hour	231	158	159	155	102	126
J	Moisture in refuse	20 per cent.	22 per cent.	18 per cent.	20 per cent.	26 per cent.	35 per cent.
K	Clinker residue	31 "	33 "	36 "	32 "	29 "	31 "
L	Combustibles by difference	49 "	45 "	46 "	48 "	45 "	34 "
M	Cubic feet of refuse per ton	54	52	73	65	54	56
N	Water evaporated at and from 212° F. per lb. of refuse	1·55 lb.	1·06 lb.	0·84 lb.	0·99 lb.	0·68 lb.	0·42 lb.
O	Wages per ton of refuse burnt	11·00*d.*	10·50*d.*	10·60*d.*	12·20*d.*	10·29*d.*	14·50*d.*
P	Value of steam generated	11·00*d.*	8·00*d.*	5·85*d.*	7·00*d.*	4·86*d.*	2·97*d.*
Q	Net cost of destruction	0·00*d.*	2·50*d.*	4·75*d.*	5·20*d.*	5·43*d.*	11·53*d.*
R	Temperature of gases in the combustion chamber	1633° F.	2000° F.	1950° F.	1950° F.	1850° F.	1950° F.
S	Temperature near chimney	585° F.	590° F.	465° F.	580° F.	495° F.	480° F.
T	Forced draught pressure	1·80 in.	1·37 in.	1·25 in.	0·90 in.	1·00 in.	1·70 in.
U	Furnace induced draught	0·37 in.	0·37 in.	0·35 in.	0·35 in.	0·30 in.	0·30 in.
V	Type of blowers used	steam-jet	steam-jet	Sturtevant	Sturtevant	Sturtevant	Sturtevant
X	Efficiency of capital outlay	1·00	0·76	0·73	0·61	0·59	0·52
Y	Amount of royalty	omitted	omitted	omitted	omitted	omitted	omitted
Z	I.H.P. per ton of refuse burnt	174	120	94	110	78	47

Then—

$$\frac{R + S}{30\,(C + W)} = X.$$

The value of the steam has been based upon coal or slack, which costs 4*s.* 2*d.* per ton, and produces 784 I.H.P., or say, 1 lb. evaporates 7 lb. of water, and its equivalent is ·0635 of a penny per I.H.P. By adopting this rate, the cost of wages and the value of steam, shown in column 1 of the Appendix, are exactly the same. Throughout the paper 20 lb. of steam is allowed per I.H.P.

In conclusion the author desires to thank all those who have kindly afforded him information upon which the statistical portion of his paper has been based.

DISCUSSION.

The President said that one of the points in Mr. Healey's paper which had particularly struck him was the varying nature, both from the calorific and the carbon point of view, of the refuse with which the destructor had to deal. That would cause very great difficulty in standardising the results which came from different parts of the country. Again, the quantity of moisture in the refuse would make a very considerable difference in the results. It seemed to him, therefore, that the author's suggestion as to some means of standardising the tests was a very admirable one, and it was admirable as regarded not only destructors, but every other form of test which could be made. That was a point which had not been sufficiently thought about and cared for in the past. One was struck with the enormous difference between the results obtained from different places. Presumably the plant was of the best description that could be used in each of those places, and therefore the greatly differing results should not appear. But if one came to examine the results very carefully, it would be found that in different parts of the country different rates of wages were paid, and different values for the carbon had been chosen, and in every case a different standard had been used in making the test. If some standard could be adopted a very distinct step forward would be taken in the matter of combining the results of tests.

Another point which had struck him was that the author

had not confined himself to any one special form of destructor in which he might be personally interested, but had taken the trouble to obtain the working results of various forms of such apparatus, and had given a useful general review of the whole subject. The waste which had been shown by the author in connection with many destructors which were not used for the purpose of raising steam, seemed to be a point that should be carefully considered at the present time when fuel was rising rapidly in price every day. Any means of raising steam for power ought to be thoughtfully examined.

The use of clinker in concrete was a matter with which he had been very familiar for many years, and he was very glad to find that the author gave a table of results showing that clinker—a material which had always been considered in gas-works to be as good as any other for concrete—had been proved by tests to be as good as, if not better than other materials which were commonly used for concrete.

The author had spoken of a furnace in which the bars lasted on an average for about twelve months. Had the author had any experience of those bars when they were partly immersed in water? He (the President) knew a system of forced draught in which the bars were made very deep, and were fitted so that the lower portion of them was in an ash-pit containing water, which helped very considerably to keep the bars cool. He would propose a cordial vote of thanks to Mr. Healey for his interesting and valuable paper.

The vote of thanks was unanimously carried.

Mr. George Watson said that Mr. Healey had raised a number of important points. Mr. Healey was well known as one of the pioneers of refuse destructors, and therefore they would expect to hear from him nothing but practical common sense, and figures based upon personal knowledge. He had been extremely moderate in what he had said as to the possibilities of destructors. A great deal of harm had been done in the past by overrating the value of destructors as steam generators. The author spoke of indicated horse-power available from a ton of refuse. He (Mr. Watson) thought that that should be indicated horse-power hours, because the horse-power obtained depended upon the rate of burning.

He did not agree with the author in putting the boilers between or over the furnaces. It was quite true that there was a loss of radiation if the boilers were put at the end of the block of furnaces, but there was a great saving in other ways. For instance, the boilers could be cleaned, and the tie bolts of the furnaces would not be interfered with; also long steam pipes would be avoided, and that was very important.

A good deal of money had been spent upon mechanical furnaces, but up to now they had not been able to compete with hand-fired furnaces. The late Mr. Whiley, of Manchester, put up a number of mechanical furnaces, but no one in Manchester regarded them as satisfactory. The input was only about three tons of refuse in twenty-four hours. The clinker formed such a very large proportion of the total refuse that the employment of mechanical fire-bars in destructors was attended by very great difficulties. Whiley's fire-bars did not break up the clinker. They shifted it forward, but so slowly that the results were quite inappreciable.

He agreed with Mr. Healey as to the importance of charging at one end and clinkering at the other. It seemed quite a wrong principle to try to work with a single-ended furnace. In a furnace of that kind there was a danger of mixing unburnt refuse with the clinker which was being drawn.

The only reliable dust-catcher which he had found up to the present time was one which depended on the principle of centrifugal force. Many engineers advocated large flues, which made the gases travel slowly. They were certainly effective to a certain extent, but only a portion of the dust was caught, while practically all of it was caught by a centrifugal apparatus.

As regarded dampers, those of steel plate were most unsatisfactory. One of the greatest difficulties of destructors had been the high temperature. Dampers buckled in high temperatures, and they ought to be always either full in or full out. A damper suspended from above, and specially cooled by means of water, was the only thing that would answer in a high temperature.

He was glad to find that Mr. Healey did not advocate high stacks. If a stack was built 300 feet high, all the people in the neighbourhood could see it, and, if they smelt anything within a radius of three miles of the stack, they would put it down to the destructor. He knew of instances in which complaints had been made even before the fires had been lighted.

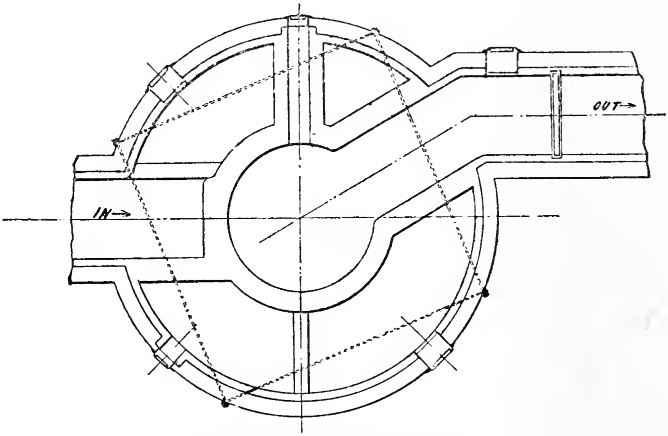
Mr. W. Worby Beaumont asked Mr. Watson if he would explain the method of application of the centrifugal principle to the collection of the dust.

Mr. Watson said that the apparatus was known as the Centrifugal Dustcatcher.

It is shown in plan in the annexed engraving, and the following is a description of it.

The apparatus consists of an outer annular chamber and an inner circular chamber or well. The inlet flue is so arranged

that the gases enter the outer annular chamber tangentially and swirl rapidly round it, thereby throwing up the greater part of the suspended dust against the outer wall. The bottom of this chamber is divided by the walls of the flue entrance and exit, and also by several special walls into pockets which serve to collect and retain the dust. These pockets are each provided with a cleaning door so that the dust can be removed without special use of the apparatus. As the gases swirl round the outer annular chamber they gradually rise to the roof of the chamber, where they can pass over the wall of the inner circular chamber or well, and then they pass downwards to the bottom of the well and out through an outlet flue provided near the bottom of the well, which passes to the chimney.



CENTRIFUGAL DUSTCATCHER

Thus the dust which has not been caught in the outer annular chamber by the centrifugal action of the swirling gases is cast downwards in this well into the pit at the bottom of it, from whence it can be withdrawn through an opening and cleaning door. The exit flue is placed slightly above the dust-pit at the bottom of the well.

Mr. BEAUMONT said that the centrifugal method appeared to be very suitable for effecting the deposition of the dust. As to the expression "horse-power" in the paper, it would be better if the quantity of water evaporated per pound of refuse were stated. The author made a statement as to the number of furnaces connected with one boiler, and mentioned that four furnaces produced 101·05 indicated horse-power, and that six

furnaces working to the same boiler produced only 100 indicated horse-power. That was only 1·05 per cent. difference between the two. One per cent. was extremely little when they considered not only the great difference between the heat value of the material from day to day, but the way in which it varied in different places. He should like to know whether the four and the six furnaces worked under precisely the same conditions, and whether that one per cent. as printed was what the author meant to put in the paper.

With regard to the use of the jet and the fan, he was glad to see that it had been recognised that a good fan was so very much more economical for moving air than steam-jets could possibly be.

The author stated that the opening of furnace doors to regulate the steam supply should not be resorted to when the use of a damper would have the same effect. That was a point which one was always wishing to insist upon, but he (the speaker) was afraid that, so long as it was easier to open a fire door than to manipulate a damper, the fire door would be used.

Referring to the average value of materials, the author said that, "taking an average of several systems, it is found that 1·26 lb. of water can be vaporised by 1 lb. of average unscreened refuse, when burnt in well constructed furnaces, and assisted by a forced draught at a pressure of 1·25 inch water-gauge. By the use of screened refuse, 1·89 lb. of water can be vaporised per pound; but, as it requires at least three tons of unscreened to produce two tons of screened refuse, there is no advantage in adopting screens." On that point he would ask the author whether the whole of the tailings, or that part of the material which was rejected by the screen, was useless for heating purposes or for any purpose. Of course the screen must reject a very considerable proportion of that which it received, but the tailings might not be useless, though the author had treated them as of no value. That had the effect of giving to the three tons of unscreened and screened refuse values of 3·75 and 3·78 according to the author's figures. One would like to know what was done with the screenings, and what was the character of the screen and the separating tackle that was used for the purpose. Vibromotor screens had been used successfully for that purpose, and he would like to know why it was that, according to the author's figures, separation did not pay.

Towards the end of the paper the author gave, in a handy form, the results of his experience with regard to the economical

value of the furnaces and destructors, as destructors and as steam-giving apparatus. If the author, instead of putting indicated horse-power, would allow the expression to be, so much evaporation per ton of materials used, the table would have a rather wider application than it could have in its present form.

Mr. W. N. Blair said that he agreed with previous speakers as to the value of Mr. Healey's paper, and also as to the modesty he had exhibited in speaking of arrangements with which he had been himself connected. The author had dealt most fairly with systems which were rivals to his own. Many of the points raised in the paper were of great interest, but without some systematic preparation it was scarcely possible to deal with them as they deserved. One of the most important things with which anyone constructing a system of destructor furnaces had to deal, was the extreme differences in the character of the refuse. The differences in that respect between one town and another were phenomenal. He did not know of any place in this country the refuse from which would not burn without the addition of fuel; but it was a fact that in Berlin the refuse was so devoid of carbonaceous matter that the authorities were obliged to actually add fuel to it to get it to burn at all. His experience was that where the carbonaceous properties of a refuse were low, greater intensity of fire, or, in other words, a stronger draught, was needed to make it burn than would be needed in the case of material which was fairly rich in carbon. The draught of a furnace must be varied to meet the character of the material.

He did not agree with the author's statement that the draught should not exceed $1\frac{1}{4}$ inch water gauge. Many of those present would be familiar with Beaman and Deas's furnaces, where the draught quoted in the table at the end of the paper was $1 \cdot 7$ inch. He had seen those furnaces burning with 5 inches of pressure indicated by the water gauge, and the normal pressure being admittedly 3 inches or a little over. It was only where those large draughts existed that a large consumption was obtained. For instance, if they took the average consumption of destructor furnaces generally to be between six and seven tons, they would get ten or eleven tons with some forced draught furnaces, that was to say, with something under 2 inches of draught-pressure; but where they had the higher pressure of Beaman and Deas's, they would get 16 or 20 tons consumption per cell per day. It was true that where there was an increased consumption there was an increased cost per ton, but that, he thought, was almost to be expected. They could

not put through the furnaces a larger quantity of material without having more labour upon it.

In connection with that point there had arisen in his mind a criticism on the author's statement as to regulating the work of feeding and clinkering the fires through the whole cycle of operations. The author had pointed out that it was often the practice for the men to feed as quickly as they could, and get round and have a rest. Anyone who was familiar with the work in a destructor establishment would not by any means wonder at a man desiring to get done with his job and sit down and have a rest. It was not light work to clinker in front of a furnace with a temperature of from 1600 to 2000 degrees. To begin with, a man did not want much clothing on, and when he had finished he would be almost sorry that he had any on at all. That being so, he did not think there was much hope of getting the men to work slowly at each furnace, so that when they had got from three to six furnaces to attend to they would occupy an hour and a half or two hours in one cycle of operations. The effect must be that a larger proportion of fire-grate area was covered with fresh material, and, that being so, the temperature of the effluent flue must be lower than if there was a greater proportion of fire at its maximum temperature.

He agreed with what Mr. Watson said with regard to dampers, and to that extent he differed from the author. A steel plate damper could not be maintained anything like true and workable where the gases were at a high temperature in the flue; but he had had cast-iron dampers about 4 inches thick formed in panels with the panels filled in with fireclay, and they had been working for four or five years and were still in a perfectly workable condition. He had had steel plate dampers, but had not been able to maintain them at all except when they got to the foot of the chimney, and at that point it was supposed that a great deal of the heat would have been taken out of the gases. In such a position a steel plate damper might be got to work satisfactorily.

There were difficulties, he was afraid, in the way of standardising, though standardising was in itself a very desirable thing in comparing the results of any mechanical operation. It would, he thought, be especially desirable with regard to the disposal of town refuse. But in that case the difficulty began with the nature of the material, and it was increased by local differences. Wages, of course, might be adjusted, but he fancied that there was a difficulty in assuming a standard rate for the price of coal. The price of coal in colliery districts might be a very low item indeed. But in London it ran up to something

very considerable, and the process which might result fairly satisfactorily in the Midlands or in Lancashire would not necessarily be satisfactory in a place where coal was at a much higher price. In fact the difference in the price of coal was very largely explanatory of the difference in the character of the refuse. In north country districts, where coal was cheap, people were not so careful to burn up every particle of it as people were in the south.

With regard to mechanical fire-bars, the author had the opportunity of making the very utmost of them that could be made in his (the speaker's) works at St. Pancras. He was fully with the author in the endeavour to make the best of them, and he had been particularly attracted with the idea, when he first saw them in Manchester, that they would be a means of avoiding a great deal of hand labour in the firing and feeding of destructor furnaces. One of the first installations of them which he saw was Mr. Whiley's, but feeling that there were weak points in them, he endeavoured to avoid them, and he adopted another form, and so long as that form of bar worked—that was to say as long as it was not impeded in its action by other influences, such as expansion caused by heat—it answered well, and in the St. Pancras furnaces it fed at the rate of 10 tons per cell per day, and all was properly consumed. But by reason of the heat causing expansion between the parts of the gearing, the feeding bars became a great trouble. They jammed and they could not be kept right. Eventually they were taken out, and since then he had been working entirely by hand-firing, with the result that about six-and-a-half tons per cell per day was got through the fires.

Of course, in an establishment where some sort of record had to be made it was easy to increase that figure, but an increase would probably be attended with an increase in the percentage of residuals, and that was a very important factor. Residuals were most difficult to be disposed of, especially when they were produced in such quantities as in a destructor establishment. At St. Pancras they were burning something like 600 tons of refuse per week, and if one-third of that was taken as residuals, there would be about 200 tons per week to be disposed of. A very considerable quantity of the clinker was used in concrete for the public works, and the rest was offered free of charge in any desired quantity to anyone who would take it away, and yet they did not get rid of more than one-half of it free. The vestry had to pay for the removal of the remainder.

As to its manufacture into paving slabs, there was a limit in

that direction. Paving slabs might be manufactured from it at a very cheap rate, but it was a question whether they were economical compared with granite concrete, which could now be bought at a very low price indeed and which would wear infinitely longer than a clinker slab. Experiments were about to be made for an actual comparison between the clinker slabs and the granite slabs. He was not, however, in a position to give any figures at the present time.

Mr. Reginald Brown said that the paper was very interesting to engineers who had to deal with destructors. He thought the title of the paper should have been "The Economical Disposal of House Refuse," not "Town Refuse." The two things were very different. Town refuse included road scrapings, gully slop, sludge from sewage, and the like. As to the proposal for making disinfecting powder from the flue-dust, he had been given to understand that the dust had a deliquescent property, which led to the particles caking together, and that would make it absolutely useless for so-called disinfecting purposes unless used directly after manufacture.

With regard to cremators, Mr. Healey stated that a few were working at irregular intervals, but many had been discarded. As a fact, prior to going to Stoke Newington, he (the speaker) had the honour of serving a council where that apparatus was working every day, and was doing so at the present time. However, with high-temperature destructors such an adjunct was not absolutely necessary, especially where the gases were brought over the hottest part of the fire and cremated within the cell itself.

As to the question of the position of the boilers, he was of the same opinion as Mr. Watson, namely, that their proper position was away from the furnaces, i.e. not between the cells, but at the end of the battery of cells. That position seemed to be the best for several reasons, although of course it did not make so good a steam-raiser.

The interesting table at the end of the paper gave the evaporative power of certain types of furnaces, together with the range of temperatures. The Meldrum furnace gave 1·55 lb., evaporated with a range of temperature of 1048° F. The Horsfall furnace gave 1·06 lb., with a range of temperature of 1410° F. The former showed an increase of nearly half-a-pound of water with 362° F. less range. Some explanation must exist as to that difference, and it was no doubt partly due to the different character of the refuse burnt. In the Meldrum case there was a refuse containing 20 per cent. of moisture and 49 per cent. of combustible matter, whilst in the Horsfall case

there was a refuse with 22 per cent. of moisture and 45 per cent. of combustible matter, or, in other words, an increase of 2 per cent. of moisture and a decrease of 4 per cent. of combustible matter per pound of refuse. If similar refuse had been treated in the Horsfall furnace the evaporative power would have exceeded 1·06 lb. of water.

Comparing the limits of efficiency of the two types of furnaces, the Meldrum gave 50 per cent., and the Horsfall 57 per cent., arrived at from the temperature given in the table; but the latter percentage could hardly be correct according to the foregoing evaporation. The temperature, for purposes of comparison, should be taken at the boiler front as well as in the furnace or combustion chamber. Taking the drop in temperature due to the length of flue in the Horsfall furnace as 350°, we should get an efficiency of 50 per cent.

A comparatively new type of boiler had been mentioned by the author. As to the vertical tubes they appeared to be very much on the principle of the economiser, and very good results could be got from the economiser, placed so as to utilise some of the waste heat of the gases after passing through the boiler.

Standardising was very desirable. He thought it could only be arrived at by taking the amount of combustible matter in the refuse. Every destructor in London and in the provinces varied as far as the composition of the material burnt was concerned. By analysing the refuse, and finding the percentage of moisture, the percentage of clinker, and the percentage of combustible matter, a fairly good standard would be arrived at. It would also be found that there should be a ratio between the temperature in the furnace and the heating surfaces which absorbed it, i.e. the boiler surfaces.

Mr. T. W. Baker said that in view of the amount of moisture which was always present in refuse it would at once be seen that some method of preparing the refuse for the fire would be very desirable. A drying hearth system of feeding, in which the moisture was evaporated before the refuse was brought to the fire-bars, was an essential in all good refuse furnaces. Then came the question of moving the material from the drying hearth to the fire proper. He read a paper before the Society in 1894, in which he referred to the Healey movable fire-bar for that purpose, and he believed it to be an absolutely new and desirable feature, but he regretted it had not proved so in use. He had recently designed, and was about to put in, some furnaces which would be fed by a ram actuated by steam, and he had driven the refuse from the drying hearth and forced it on to the fire-bars where it became incinerated. The

stoker moved a small lever and moved the charge to the furnace as it was required, and, with the exception of occasional raking, a level quantity of fuel was kept upon the bars.

Then came the question of clinkering. The labour of clinkering was probably equal to that of making the fires. Therefore, if mechanical means could be employed by which the clinker could be raised from the bars and brought to a suitable place for being drawn out, or pulled out, or allowed to fall out of the furnace, so that the stoker did not have to remove it, he would be relieved from much unpleasant labour. Such points in connection with refuse destructors needed to be very carefully looked into, and they would undoubtedly have the effect of diminishing the cost of labour per ton, which appeared at the present time to be a great question, particularly with London refuse.

It was difficult to say which class of mechanism or system was the best for any particular refuse, and the system of standardisation of results mentioned by the author would be extremely desirable if it could be brought about. He had no doubt that a proper discrimination between the various mechanical means and their results would assist materially in reducing the cost of the disposal of town refuse.

Mr. E. J. Silcock said he was very pleased to hear that Mr. Baker had designed a mechanical means of stoking which would throw the material on to the fires. One of the points which had struck him (Mr. Silcock) was that practically they had got no fresh form of furnace and no fresh form of mechanism connected with the furnaces from the time of the very first destructor. No doubt there had been great improvements in details here and there, but what was wanted was a fresh form of furnace which could be fed mechanically and would not need so much labour for stoking and clinkering. Mr. Blair had pointed out the great personal inconvenience to which the men were put in carrying on that work. The work was very hard, and it was rather a reflection on engineers that for twenty years no improvement had been made in the matter of feeding, and very little in regard to clinkering.

As to the quantity of material which could be burnt in a furnace, the author said that, roughly, about forty tons in six days was the amount that was usually burnt, or six-and-a-half tons a day for a furnace with 25 feet of fire-grate. The question was not altogether one as to how much material could be burnt on a fire-grate. The point to be decided was how much could be burnt for the least possible cost. There was an economical rate of burning which every town must decide for itself, and which depended on

a variety of circumstances. In London, no doubt, the cost per ton would be very much higher than in the provinces. At Leeds, where the destructors had been used for more than twenty years, they had come to the conclusion that the lowest cost for which they could destroy one ton of refuse was two shillings, including everything. If they attempted to force the furnaces and to put more material through the cost per ton was increased, and that was not true economy.

As to the amount of steam which could be raised from house refuse, he was glad to see that the figures given in the paper fully confirmed the opinion which he had held for a very long time, namely, that in most cases 1 lb. of steam from 1 lb. of refuse was the most that could be obtained in every-day working. In the paper 1·26 lb. of steam per pound of refuse was given as the average of a number of systems; but the author must excuse him for pointing out that in the table in which the average for six systems was given, that average worked out as 0·92 lb. of steam per pound of refuse. At Shoreditch, where there existed probably the best arrangement for utilising the highest amount of heat from the refuse, they obtained not quite 1 lb. of steam for 1 lb. of fuel.

He desired to emphasise the remarks made by Mr. Beaumont in favour of using the expression "water evaporated" rather than "horse-power." Horse-power was certainly a somewhat ambiguous term; it depended on the "personal equation" of the engine, the way in which it was worked, and a variety of other circumstances, which rendered it an uncertain quantity and very unsuitable for use in discussing a scientific subject before engineers.

The position of the flues and the point at which the gases were taken from the furnace were most important matters. He was glad to see that the author advocated that the gases should be extracted from the furnace at the very hottest part. That was one of the most essential points in designing a furnace, and its importance was discovered in Leeds at about the same time as it was discovered in Bradford. The original Fryer furnace had its outlet near the point where the charge went in, and consequently the gases given off by the drying of the wet refuse as it went into the furnace were mixed with the other products of combustion, and went to the chimney without being consumed. Whereas if those gases were taken to the point where the highest temperature was obtained, viz. near the front of the furnace, they were completely burnt, and the result was that they secured perfect combustion and a proper and regular temperature of the furnace.

With regard to the height of the chimneys, he quite agreed with the author and Mr. Watson that the height was in many cases very much greater than was necessary. In Leeds they had twelve cells working with a chimney 70 feet high. On the other side of the road there was a block of cottage property, and in the neighbourhood were several factories in which people worked, and they never had any complaints, either from the small houses or from the factories. Therefore he thought that a very high chimney was unnecessary. In another case, however, the corporation had put up furnaces with a stack 80 yards high, but that was in a very special position, and the destructor was situated in a valley.

As to the residuals, there was one use to which they could be put, perhaps not in London, but at all events in the provinces, and that was in connection with what was very much talked about now, namely, sewage purification by means of bacterial filters. There was great difficulty in many places in finding material with which to fill the filter beds, and the hard clinker from destructors was very suitable for the purpose, and such filter beds were a means by which clinker might be very well got rid of at a good price.

Mr. John Samson said that last year he saw at the works of Messrs. Joseph Baker and Son, Willesden Junction, a destructor in course of manufacture for the city of Manaos, Brazil, which appeared to be a great improvement upon what had hitherto been used. It comprised all the necessary features of a good destructor. There were special arrangements for drying the refuse before it was fed into the furnace, and for feeding the furnace and taking away the clinker. Manaos was the capital of the State of Amazonas, in Brazil, and the place was so wealthy, owing to the boom in rubber, that the city was getting everything of the very best. The apparatus designed for that city contained features which he thought were superior, scientifically and theoretically, to anything that was described in the paper. The destructor was to be used for producing electricity for the lighting of the city. The refuse was fed into a hopper, the base of which formed an inclined roof to the furnace. Consequently, as the refuse moved downwards it was rapidly dried and heated. The vapours and gases arising from the drying process were drawn down a flue, and subsequently passed upwards through the furnace bars where they were effectively consumed, thus contrasting favourably with the destructors of the usual type in which the gases of distillation were evolved in the furnace chamber itself, and complicated the problem of combustion therein. By the time the refuse

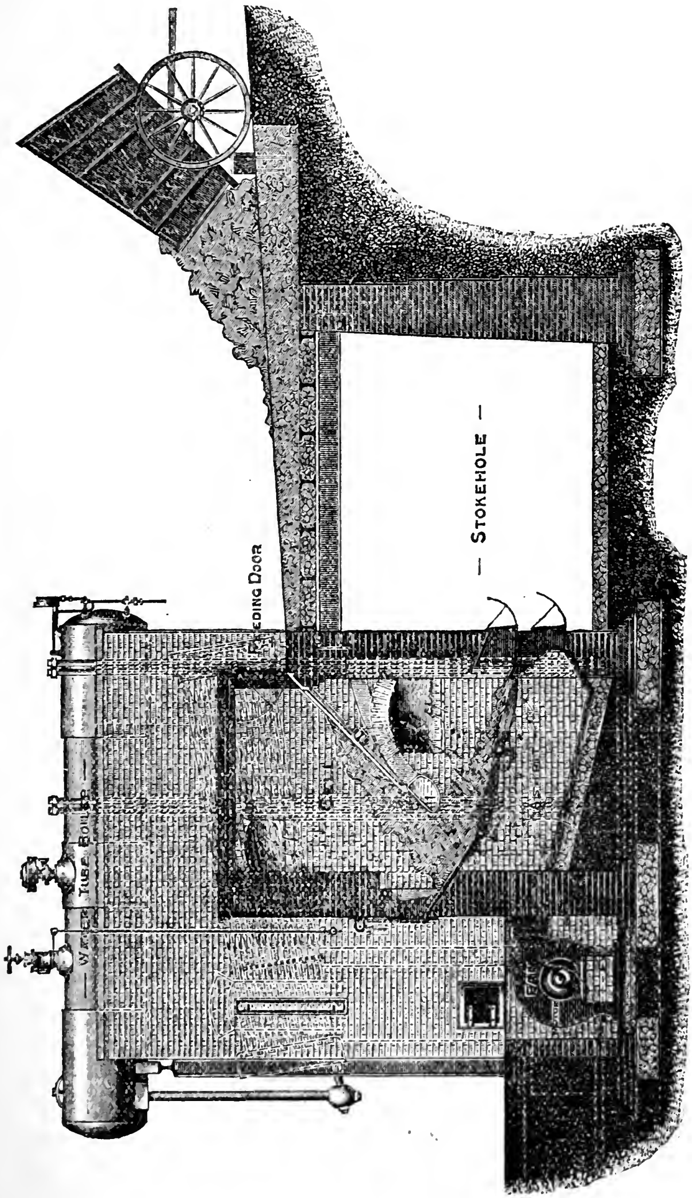
reached the furnace it was raised to a high temperature, almost burning in fact. The stoking door was at the back, so that the mass of refuse came between the fireman and the furnace. The furnace bars were set at a steep angle, and stoking was greatly facilitated thereby, also the removal of the clinker.

[By courtesy of Messrs. Baker and Son, a sectional elevation of this destructor is given on the opposite page.]

Mr. Somerset Butler, referring to the standardising of the working of destructors, said that it seemed to him that there was one vital point in connection with the matter, namely, the question of the cost of labour. It was very often said that the cost in one town was a shilling, while in another it was two, and in another sixpence. The cost of labour was a point which had not been brought out very clearly by the author. In different towns the refuse varied in cubic capacity to a very large extent, and, as far as the standardising of the cost of labour was concerned, there seemed to be only one method of doing it, and that was to state how much one stoker would do in one hour, or how many cubic feet of refuse he would move. In some towns in the north of England the weight of the refuse ranged from forty to fifty cubic feet to the ton, whereas farther north (in Scotland), and again in the south of England, there were from 80 to 120 cubic feet to the ton. To move a ton of refuse which was 60 cubic feet to the ton meant about half the work of moving a ton of refuse containing 120 cubic feet to the ton. That was the reason why he suggested that the standardising should be based, not upon the weight, but upon the number of cubic feet per ton.

The President said that, before calling upon Mr. Healey to reply to the discussion, he would refer to the question of the employment of fans as against steam-jet blowers. It had long been recognised in gasworks that, to draw the gas from the retorts and to pass it through the remaining portions of the plant, a far better effect was got by means of exhausters or rotary fans than by means of the steam-jet exhaust. Mr. Baker had referred to the use of a plunger for forcing the fuel into the furnace. That was the method adopted in a hydraulic stoker for supplying the coal to be carbonised in a gas retort, and it was only utilising a principle which had been adopted for some years past for that purpose.

Mr. Healey, in replying upon the discussion, said that there seemed to be rather a consensus of agreement upon the paper, so that it was somewhat difficult for him to reply to the various remarks. Mr. Watson agreed pretty well with the



BAKER'S REFUSE DESTRUCTOR. (Vertical Section, showing Interior of Cell.)

greater part of the paper. The centrifugal dust-catcher he had mentioned was a good thing. He (Mr. Healey) had omitted to speak of that appliance, not because he was not aware of it, but because he thought that his paper was too long already. As to the steel dampers, although he had constructed many hundreds of Siemens furnaces, he had never found anything answer so well as steel dampers one-eighth of an inch thick. They should be as thin as possible. When the damper was found to be nearly melting it could be taken out and straightened. He agreed that destructor dampers should be either out altogether or in altogether. Mr. Brown, from his remarks about boilers, appeared not to have studied the diagrams illustrating the paper. If he had done so, he would not have arrived at the conclusion that the apparatus in question was a kind of economiser. He would find that there was no point at all of comparison with an economiser. In the economiser there was an upward and downward flow continually. The boiler outlined in Fig. 12 had a very different circulation, which was clearly shown.

As regarded the percentage of moisture in the refuse, they all agreed that, in order to produce the table and to make any valuable use of it at all, they must take into account in each case the percentage of moisture in the various kinds of refuse and the percentage of combustible matter. They must also take into account the superficial area of the heating surface of the boilers. The results would be found to vary. In the Lancashire boiler in the table there was 915 square feet of heating surface; in another boiler, 2236 feet. All such matters must be taken into account. Then came the question of velocity. That was a point which had a great deal to do with the matter. If the gases were rushed through, the work was not so well done. The gases must go through at a slow velocity in order that the heat might be taken out of them. That was the method he advocated and adopted, and he was pleased to say that so far it had given very good results.

Mr. Silcock had referred to the average of 1·26 lb. of water which was given as the amount vaporised by 1 lb. of unscreened refuse under different systems. The systems mentioned were not the same systems as those mentioned in the table of results. That accounted for what appeared to be a discrepancy. The same results had been obtained from week to week, without any trouble at all, in a furnace in which he had no interest whatever. That was one of the systems mentioned in the table of results. They all knew that refuse varied very much. If they wanted

to compare any systems named in the table of results, the only way would be to send for a few wagon-loads of stuff from the places whose systems were to be compared. If that was done, the results could be relied upon.

Mr. Butler had gone into the question of the variation of the quality. Perhaps rather too much had been said with regard to the variations in quality and weight. The figures given in connection with the consumption of the furnaces were merely fixed upon as a basis of comparison. He did not mean to say that the figures represented all that the furnaces could do. When there were very considerable variations they were due to the different kinds of refuse which were used. As to the screening of the refuse, he did not believe in it at all. If only the same results were obtained by screened refuse as by unscreened refuse, he did not see what was gained by screening. As to the plunger to which Mr. Baker alluded, some thirty years ago he (Mr. Healey) carried out some experiments with a fuel plunger at Barrow-in-Furness. The fuel was put into a 3-foot hopper and lifted, and as the fuel was brought up to the top it was burned, and the feed was automatically continued. He agreed with Mr. Blair's remarks as to the dampers of the furnaces: they should either be fully open or quite shut.

As regarded standardising there should be no difficulty, and as to the cycle of operations there should be no difficulty either. What was wanted was to start the first furnace at the hour, and then make a pause, start number two at the half-hour, and so on for the full cycle, making a decided pause between the different furnaces. He agreed with Mr. Blair that it was most difficult to get the men to do that which they ought to do, and to work the cycle in that way; but until they did so the results would not be different from what they were now. If the temperatures were to be uniform, the cycle must be worked properly.

Mr. Blair said that the fire-bars were not a success, but he omitted to state the reason why they were not a success. They must be kept clean and lubricated as mentioned in the paper. If the dust was not kept out they would wear away. If the wall boxes were made properly the dust particles could not get in. If they were kept out the bars would last longer. That was the explanation of the reason that the bars wore out. He would ask Mr. Blair to state whether or not the boiler mentioned in the paper was a success, and if it had been working three years and a half as stated, and further, had the system advocated by the author been extended at St. Pancras?

Mr. Blair said that it was a fact that the boiler which the author spoke of had been working for three years and a half continually, except on holidays, such as at Easter, when the flues were cleaned out. He was so satisfied with it that he had had two more water-tube boilers put down.

HEALEYS 1887.

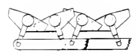


FIG. 1.

HEALEYS 1892

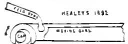


FIG 2

FIG 3

HEALEYS 1886 & 1892.

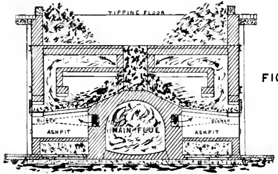


FIG. 5.

WARNER'S 1892.

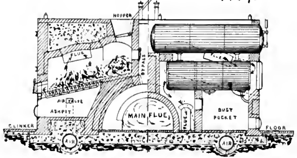


FIG 7.

HEALEY'S SYSTEM 1880.

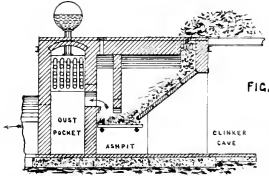


FIG. 9.

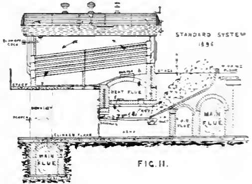


FIG. 11.

BOULNOIS, WOOD, & BRODIE 1891 & 1895.

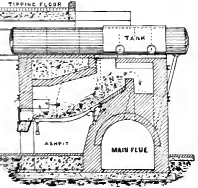


FIG. 4.

HORSFALL'S FURNACE. 1895.

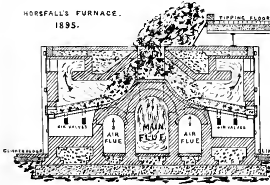


FIG. 6.

BEAMAN & DEAS. 1893.

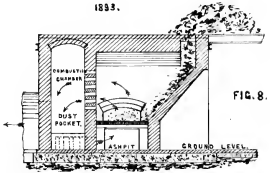
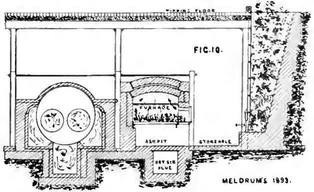


FIG. 8.



MELDRUM'S 1893.

HEALEY'S BOILER 1900

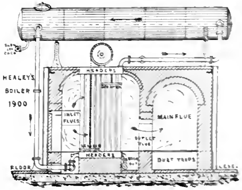


FIG 12

June 11*th*, 1900.

JOSEPH WILLIAM WILSON, Past-President, in the Chair.

NOTES ON ELECTRIC TRACTION.

By Algernon Hamo Binyon.

In introducing a few general notes for discussion on so broad a subject as electric traction, the author has principally aimed at giving a bird's-eye view of some of the latest ideas and apparatus in the best modern practice. The great developments now taking place in working tramways electrically will, he thinks, fully justify his bringing before the Society a few points on the subject.

The great tide of human traffic in London and New York is illustrated by the following table. At present about 81 per cent. of the annual London traffic is worked by the old-fashioned horse and cable cars.

Table I.

LONDON.

	Passengers.
Tramways (horse and cable)	309,000,000 or 45 per cent. of total traffic.
Underground railways	128,400,000 or 19 „ „
Omnibuses	248,600,000 or 36 „ „
Total	686,000,000

The population of 5½ millions travels 124 times over.

NEW YORK.

	Passengers.
Electric tramways	517,000,000 or 70 per cent. of total traffic.
Elevated railways	228,000,000 or 30 „ „
Total	745,000,000

The population of 3½ millions travels 210 times over.

MANHATTAN BROUZ (New York City).

	Passengers.
Electric tramways	321,000,000 or 65 per cent. of total traffic.
Elevated railways	183,400,000 or 35 „ „
Total	504,400,000

The population of 2⅛ millions travels 234 times over.

The underground railways do not at present take a sufficient share of the traffic. This will, no doubt, be altered when the Central London, and the District and Metropolitan Companies, are working their lines by electricity. The omnibus traffic will be greatly reduced by the use of electricity both for tramways and railways. England is the ideal country for tramways, being so densely populated.

We cannot expect to destroy the lead America has over us in the production of electric traction material, but in time it is to be hoped that our manufacturers will take this matter up seriously. If they do not, all contract orders of any magnitude will still cross the Atlantic. There is plenty of scope for our English manufacturers to make all machinery for our use without having to import it. The best poles, brackets, trolleys, cars, etc., are made in England.

The following table gives a comparison between the railways and tramways of America and the United Kingdom :—

TABLE II.

RAILWAYS.

—	Population.	Area in square miles.	Number of persons per square mile.	Number of persons per mile of railway.	Square miles of country to one mile of railway.
America	100,415,400	15,806,154	$6\frac{1}{3}$	433	68
United Kingdom ..	39,829,765	120,137	$331\frac{1}{2}$	1872	$5\frac{2}{3}$

—	Capital Expenditure upon Railways.	Gross Receipts. (a)	Total Expenses. (b)	Per cent. ratio (b) to (a).	Passengers carried.	Total Mileage.
	£	£	£			
America	2,354,200,000	219,000,000	154,000,000	70	544,000,000	231,988
United Kingdom	800,000,000	77,025,000	40,100,000	52	755,200,000	21,277

TRAMWAYS.

—	Capital Expenditure upon Tramways.	Gross Receipts. (a)	Total Expenses. (b)	Per cent. ratio (b) to (a).	Passengers carried.	Total Mileage.
	£	£	£			
America	280,000,000	32,850,000	22,700,000	68	3,000,000,000	14,000
United Kingdom	13,000,000	3,540,000	2,640,000	75	480,000,000	1,000

Overhead Trolley System.

Without entering into the controversy respecting the different electric traction systems for tramways, the author may safely say that the overhead trolley wire is—

(*a*) The most efficient and economical.

(*b*) The least expensive in first cost and upkeep, easily maintained and repaired (see Fig. 1, repair trolley wagon).

(*c*) Safe and reliable.

The trolley wire is made of hard drawn copper, with a tensile breaking strain of from 21 to 23 tons to the square inch, and 98 per cent. electric conductivity. The usual size of trolley wire is ·325 inch in diameter, but ·364 and ·409 are also used in Liverpool, Leeds, and in a great number of extensions now being erected. More copper in the trolley wire saves it in the feeders, and, combined with the flexible suspension bracket (Figs. 2 and 3), makes a more substantial overhead structure, reduces sparking, and for city work is more satisfactory. The trolley wire can be fixed—

(*a*) Centre pole bracket (Figs. 2 and 3, flexible suspension).

(*b*) Side brackets (Figs. 4 and 5, rigid suspension).

(*c*) Span wire, with rosettes attached to the houses.

(*d*) Span wire with side poles.

(*e*) *c* and *d* combined.

The adoption of any of the above is governed by the requirements of local conditions. The central strung trolley wire, known as the American system, runs directly over the centre of the track. It has many merits, but it cannot be denied that sometimes it entails very long bracket arms, which are not always beautiful.

The side trolley, which has been principally developed in England, eliminates the unsightliness of long brackets. Poles, as shown in Fig. 2, are now being erected in London. The trolley wire can be even 10 or 12 feet out of the side of the track; the swivelling trolley will follow the wire out at any angle, but the best working limit is an angle of 45° formed by the trolley arm and the trolley wire when seen in plan. A type of swivelling trolley is shown in Fig. 6; three thousand of these are in present use.

When the London United and the London County Council Tramways are finished we shall have a complete net of quick travelling lines from the suburbs to London. The author may here mention that in future the competition of these electric tramways will be strongly felt by the railway companies, who will in time, no doubt, be forced to adopt electric traction to

cope with suburban traffic within a radius of from 10 to 25 miles round London, this being probably the range within which competition will exist, and beyond which the steam locomotive will beat its rival.

Power Distribution.

Having regard to our Board of Trade regulations for the drop of voltage, and to the economical transmission and distribution of power, a 500-volt continuous current station seems generally to reach its limit at 5000 kilowatts output. Beyond this a 3-phase high-tension current (25 to 50 cycles) is transmitted from a central power station to a number of sub-stations at high initial tension of 5000 to 20,000 volts, and through static and rotary transformers is reduced to 500 volts direct current, adapted for the railway motors in common use.

The distance of transmission, the amount of power, and the nature of the load, are the factors determining where a continuous current or multiphase system is best in each particular case. It is only by this means, i.e. by adopting high voltage and polyphase transmission, that most economical working can be obtained, and the investment on copper and on conduits, etc., can be kept within reasonable limits in a large city plant.

Sub-Stations.

The economy of sub-stations in working, the elimination of smoke, vibration and noise, and the fact that they take up very little room, make them preferable to completely separate generating stations. Increasing the number of sub-stations involves—

(*a*) Lower efficiency of transformation.

(*b*) Higher first cost of plant.

(*c*) Increased maintenance and attendance expenses.

These are counterbalanced by—

(*a*) A saving in number of feeders and distributors.

(*b*) A higher efficiency of transmission, due to less feeder losses.

(*c*) Elimination of undue drop in volts in individual feeders, due to congested overload.

(*d*) Simplicity in switchboard, better general results, and more economical and uniform running.

Estimating the cost of a sub-station (say within 12 or 18 miles) with rotary converters at 5*l.* per horse-power complete, and 2*l.* per horse-power for the line, the cost of output at the

sub-station above that given at the generating station bus bars is about one farthing per kilowatt-hour.

No general rules can settle the choice of the best number of sub-stations. Each particular case has to be worked out on its own merits; for matter of argument, if we have a large uniform area equally distributed with 1000 or more kilowatts per square mile, economy would best dictate a distribution of half-mile radius. The number of sub-stations will diminish, and the economical radius of supply will enlarge, with smaller supply densities and with unevenness of distribution.

Dublin, Middlesbrough, and the Central London are the only three places in the United Kingdom where multiphase currents are actually in use. The London United Tramways, Glasgow, and the Metropolitan, will prove that true economy and not fashion has led to the choice of the multiphase system.

Combination of Lighting and Traction Plant.

The question of combining lighting and tramway plant has had the careful investigation of the greatest experts at various times. Mr. H. F. Parshall, Lord Kelvin, and Dr. John Hopkinson found that there would be a direct disadvantage in such a joint supply in Bristol and Sheffield. The following points are worthy of notice in regard to large stations. The maximum load in lighting and traction often occur at the same time, so that the total capacity of the station would have to be designed for this combined possible maximum.

The switching gear and switchboard arrangement differ for the two purposes, as the arrangements for electric lighting are necessarily much more complicated in order to keep the voltage constant, while in traction work a much greater range of voltage is permissible without discomfort to the working system.

The unit cost of energy for electric traction where the full capacity of the machines is used for longer working hours is, in many cases, more than 25 per cent. less than that for lighting. The average price per kilowatt for lighting is given in the following table (see next page), taken from Mr. H. A. Foster's figures. English stations compare favourably on the whole with equal sized stations in America and elsewhere.

Mr. Parshall, in his report to the Glasgow Corporation, showed how electricity for traction purposes for that city would cost 3·8 times less than (1·93*d.*) that used for lighting. It is also interesting to note that the amount of electricity generated for traction purposes above the average load would require a

COST PER KILOWATT-HOUR OF VARIOUS LIGHTING STATIONS.

Stations.	Labour.	Fuel.	Supplies and Office.	Total.	Remarks.
	d.	d.	d.	d.	
"Ideal" station (Crompton), 5,000,000 kilowatts output	·2	·27	·85	1·32	
23 average English	·72	1·11	·97	2·8	
14 municipal (U.S.A.)	1·25	·865	·805	2·915	Continuous current arc.
5 " "	1·22	1·13	·63	2·98	Incandescent arc-lamps.
1 new " "	·758	·99	·34	2·97	
6 (U.S.A.) mixed output, 5,300,000 kilowatts	..	·47	..	2·36	Fuel 20 per cent. of total cost.
5 (German) stations, 1,907,900 kilowatts output	1·09	..	..	2·34	

The cost per kilowatt-hour of the proposed Glasgow electric traction station, 26,000,000 Board of Trade units per year, is	·495
Against the cost of electric lighting in that city per Board of Trade unit (3,000,000 units)	1·93

plant of nominal capacity of not more than one-third that necessary for a lighting station, owing to the machinery working longer. It is for times of trouble one has to be prepared, and completely separate units seem to be the wisest policy from that standpoint. Although for small roads, like Plymouth and others, the combination of lighting and traction dynamos on the same shaft may no doubt prove a success, it is always wise not to have too many eggs in the same basket, unless they are quite separately protected.

Double-current generators are capable of delivering their current either direct or alternating as the load is near or far from the station, and would seem to solve the problem, and may in future play a very important part in bringing the traction and lighting load on the same dynamo. For structural reasons their speed must be high, therefore our English type of quick revolution engine or steam turbine would probably prove adequate for this purpose, say for 100 to 400 kilowatt capacities or more.

The direct current three-wire system with lamps at 250 volts between the centre wire and the outers, and 500 volts between the outers, would supply a radius of from two to five miles; but beyond this the alternating current terminals of these generators should be connected to a bank of transformers to the distant sub-station (with rotaries) for traction service, and to another bank of transformers which would supply the conductors

for incandescent lamps and stationary motors beyond the direct current radius.

A completely separate set of mains should be adopted for the two systems, and batteries would have to be largely used to keep up the voltage to equalise the load on the system and to obviate any risk of stopping the supply due to accidents. This method is likely to make great strides where Corporations wish to run their own tramways, and which not being of great magnitude would not justify a separate traction equipment.

Batteries.

For potential regulation in traction work a comparatively small battery is required, since by changing the potential of the booster from time to time during the day the charge and discharge can be kept very low. For load regulation, the battery should have a capacity of one-third the maximum output of the station. The average load of the station may be made the maximum load of the engines, the battery taking care of the fluctuations. No limitations restrict the size of plates, therefore the charge and discharge can be within normal rates.

Cells are generally so designed as to grow in capacity with the other parts of the system of a power-station. This is done by allowing room in each cell for extra plates. Their purpose in railway work has been primarily to take care of sharp fluctuations for equalisation of load in sub-stations, although in many cases the rapid growth of traffic has made the battery, in the central station, carry for a short period part of the load. In emergencies it would prove a useful stand-by until an extra engine was switched in. The storage batteries are not always provided with boosters, but are often directly connected across the line at points distant from the power-station, and their charge and discharge is regulated, partly automatically by the drop of potential on the line and feeders, and partly by the use of additional feeders thrown in and out as required.

Engines.

The progress in mechanical improvements in recent years has been so great that engines of all kinds operate well, and criticism of one as compared with another must be of course of a general nature. An engine to operate in electric railway practice must mechanically be of most substantial nature, as there are far greater fluctuations in load in this work than in any other kind (i.e. instantaneous and erratic changes from

maximum to minimum), which necessitate special designs to fully meet all requirements. It must not only regulate under these severe conditions, but be proportioned in its entire construction to stand heavy overloads. The secret of economical designs is to distribute the material in the line of strains as nearly as practicable, thus eliminating the trouble of transverse strains resulting from pressures transmitted out of the direct line.

The usual practice is to employ engines, the greatest efficiency of which is reached when running at about two-thirds of the maximum power required. As the average load in traction work is generally from one to two-thirds of the maximum, it follows, that if the engine were built with a view to taking full load, it would ordinarily be working with a very low efficiency.

With a heavy fly-wheel and sensitive governor an engine can cope economically with this special work, if designed to operate economically at about the average load, the fly-wheel having such a weight that its live energy is able to give out the extra amount of work called for by sudden maximum demands. An engine should not be of such a capacity for excessive overload as a generator, which can endure 50 per cent. for several hours, and more than this, without undue heating or sparking for short periods. The element of time does not enter into the engine problem, but it becomes a question of how much the engine can actually lift by main strength without taking the governor to an extreme which shall slow down the speed.

An engine should be capable of running continuously at 20 to 25 per cent. above its rating, and 50 to 65 per cent. for short periods, at maximum loads, but it should be slightly weaker than the generator to obviate the danger of burning it out. In many cases the capacity of the engine should be determined without reference to condensing. Should the condenser become choked or disabled, or leaky, and the vacuum be poor, or lost entirely under sudden fluctuations, the working of the machine would not be impaired.

A uniform speed is especially important where compound-wound dynamos are run in parallel direct on to the line. If the momentary difference in speed between two engines exceeds very narrow limits, the voltages of the machines differ, and cause very heavy currents in the equalising bars, and largely increased core losses. If this is too great generators may even be reversed.

A traction station, where compound-wound dynamos are used, should be so arranged that, if the normal load be suddenly thrown on or off an engine, the speed shall not vary more than

2 per cent. In some cases a maximum variation of $1\frac{1}{2}$ and $1\frac{1}{4}$ per cent. is all that is allowed. In cases where shunt-wound generators with heavy batteries of accumulators run in parallel on the line, the question of regulation is not so important, as the batteries take care of all fluctuations and keep an even load on the engines.

In polyphase work the engine should not produce by variation of angular velocity a phase displacement of more than 5° per half cycle, or an angular velocity not exceeding $\frac{1}{4}$ to $\frac{1}{2}$ of 1 per cent. during one revolution. The efficiency of first-class large Corliss engines for traction work varies as follows:—

	Per cent.
Rated load	90–95
$\frac{3}{4}$ load	86–93
$\frac{1}{2}$ load	80–90
$\frac{1}{4}$ load	60–80

Data on modern electric traction plants are very scarce; perhaps the most careful estimates yet given are those of Mr. Philip Dawson* and of Mr. Emery. The latter has calculated the cost of a horse-power year in a first-class modern steam plant with engines of about 500 horse-power, and working an average of 24 hours daily, to be a trifle less than 8*l.*, and in a 20,000 horse-power plant this figure is reduced to a little less than 6*l.*

The following table shows the cost per horse-power per hour, with coal at 13*s.* 9*d.* per ton. This table is based upon 500 horse-power units.

TABLE III.

Type of Engine.	Operating Expenses (3080 hours).	Fixed Expenses (3080 hours).	Total (3080 hours).
	d.	*d.*	*d.*
Simple high-speed non-condensing	·435	·140	·575
Simple low-speed non-condensing	·384	·145	·529
Compound high-speed non-condensing ..	·359	·130	·489
Special triple high-speed non-condensing ..	·337	·143	·480
Simple high-speed condensing	·315	·119	·434
Simple low-speed condensing	·285	·127	·412
Compound high-speed condensing	·293	·123	·416
Compound low-speed condensing	·263	·129	·392
Special triple compound condensing	·260	·130	·390
Triple compound low-speed condensing ..	·241	·145	·386
Triple compound low-speed condensing ..	·230	·155	·385

	d.
Mean total expenses for 3080 hours	·392
Mean total expenses for 7300 hours = about	·308
Mean of total average..	·35

* 'Engineering and Electric Traction Pocket-Book.'

Fig. 7 is a vertical cross compound, the largest yet made for traction work; eleven of these are being erected in the Metropolitan station, New York. These vertical Allis engines run at 75 revolutions per minute, indicating 4500 horse-power at greatest economical load ($\frac{1}{4}$ cut off), but are able to run continuously at 6000 horse-power, or for a short time at 7000 horse-power. They are cross-compound condensing, with Reynolds-Corliss valve-gear, with separate wrist-plates for the steam and exhaust valves, which are in the cylinder heads.

The valves for the high-pressure and low-pressure cylinders are worked from two separate eccentrics, but both controlled by one governor. A safety governor, which prevents the speed exceeding the normal by more than 5 per cent. under any circumstances, is also fitted. The speed of the governor can be adjusted from the switchboard. The high-pressure and low-pressure cylinders are cross-connected respectively to steam and exhaust piping, so that either cylinder can be operated separately. Steam is supplied at 160 lb. per square inch. The cylinders measure 46 inches by 86 inches by 60 inches stroke. They are not steam-jacketed, but there is a reheating cylindrical reservoir, 32 feet long and 5 feet diameter, between the cylinders. Each engine stands 38 feet 3 inches above its foundation, and occupies a floor space of about 43 feet by 24 feet.

The shaft is hollow, 16 inches internal diameter; the external diameter being 37 inches in middle, 34 inches at journals, and 30 inches at the cranks. It is 27 feet 4 inches long and weighs 70,000 lb. There are two journals, 34 inches by 60 inches. The cross-head is of cast steel, wedge adjusted, with Babbit faced shoes. The cross-head and crank-pins measure 14 inches by 14 inches. The connecting-rod is 13 feet 8 inches long. The fly-wheel is built up of steel, weighs 150 tons, and is 28 feet in diameter. The rim is of cast steel, 2 feet 5 inches deep, and 2 feet $4\frac{1}{2}$ inches wide, in ten segments, joined together by steel links 30 inches long, 10 inches wide, and 5 inches thick, shrunk in at the sides. There are 80 plates of steel, $1\frac{1}{8}$ inch thick, riveted on to each side of the rim by 3-inch steel rivets, closed by hydraulic pressure. The fly-wheel, cranks and generator spider were forced on the shaft by hydraulic pressure, $5\frac{1}{2}$ tons per square inch. The total weight of engine and generator is 700 tons.

Each engine is directly connected to a G. E. 3-phase 3350 kilowatt generator with 40 poles, giving 25 cycles at 6600 volts and 75 revolutions per minute. They are of the revolving field type, with external stationary armature. The field-ring is mounted on a spider with eight arms cast in one

piece, with hub, which is keyed to the shaft, and bolted direct to a projecting cylinder on the fly-wheel hub by 16 $2\frac{1}{2}$-inch bolts at a radius of 4 feet. The illustration of this engine (Fig. 7) will give some idea of the 4500 horse-power engines being built for the Glasgow tramways, although these will slightly differ in various points of design.

Switchboards.

In determining the best design and arrangement for a switchboard in the engine-room, the following points should be kept in mind. It should not be placed over steam piping, it should not shut out any light, and should be so situated that instruments can be easily read. The capacity and voltage of generators, the capacity and number of feeders will materially affect the general design. Bus bars and main cables from a generator to a switchboard should not be worked at a current density above 400 to 600 amperes per square inch, as the heat due to the increasing resistance of small areas proves to be the source of a great loss.

Fuses.

Overloading endangers both circuit and central station machinery; a large demand on the line may injure the station machinery, or, conversely, a de-arrangement in the station may damage the line by an overload of current. The simplest safety appliance is the fuse, but experience has shown that its melting point is difficult to ascertain with accuracy to obviate too frequent opening of circuits with slight increase in current, or not to afford enough protection by allowing dangerous overloads for too long.

Experience has also shown that the action of an alternating current has a disintegrating effect upon fuses, which causes them to blow after short use, necessitating constant supervision and renewals. This molecular change, produced by the current, leads to crystallisation and makes the material brittle, and causes the fuse to go below its rating after a short time. If it is made of larger capacity to obviate interruption of the circuit then it will fail to protect the apparatus against overloading during the early part of its life.

Copper and aluminium are not adaptable for fuse metals, owing to the high temperature required for fusing; and to work with any reasonable sensitiveness they have to be main-

tained at a red heat. Fuses are sluggish and generally unreliable, as position, length, age, oxidation, shape, composition, temperature of terminals, all affect their fusing point.

Automatic Circuit-Breakers.

A great many methods have been employed for mechanically rupturing the current in a circuit by its own effect, after it has reached a pre-determined point. The magnetic power of a coil is generally used to actuate an armature, which in turn releases the switching device. Expansion by heat has also been tried for disconnecting the circuit, but the time constant caused by the current itself in this fashion is far too slow to be effective, as fuses unfortunately very often show us.

In order to accomplish the desired result in a circuit-breaker, the time between which the abnormal current rises in the circuit to be controlled and the actual opening should be as short as possible. It should become less and less in proportion as the strength of current increases, because a short circuit quickly assumes large proportions. Any circuit-rupturing device should act instantaneously after the current has commenced to rise above the set value, so that the rupturing device can break the circuit before the current has attained such a dangerous volume as would be destructive to any rupturing contact. The quicker this action the better, to both the generating apparatus and the distributing system.

The actual breaking of the circuit should be performed positively and with certainty; yet to sever a high potential would cause an arc which would seriously interfere with the proper action of the contact surfaces. Provision must be made so that this arc will occur where it cannot damage the current-carrying parts of the breaking mechanism, and in many cases a shunt is used to reduce these evils. In the B.T.H. type the spark is blown out magnetically, in the I.T.E. circuit breaker it is located to carbon contacts, where deleterious effects are obviated by the vapour resulting upon the formation of an arc which has a high resistance, also by the refractory nature of the carbon itself, and by a counter electromotive force, approximating to forty volts.

High-Current Circuit-Breaker.

The author will now proceed to describe the latest type of circuit-breaker for high currents up to 10,000 amperes and more. The inverse time element is adopted in its design, that is, the time of opening the circuit becomes less and less as the conditions of the circuit protected approach nearer and nearer the short circuit. This device will open the circuit in $\frac{1}{60}$th part of a second under the latter condition (Figs. 8 and 9).

Main contacts consist of a number of fine springy leaves extending across the body of the instrument and forced back by a toggle joint, connected to the handle, giving a pressure of many hundred pounds with considerably less force than that required to manipulate the older types of breakers. The leaves are slightly curved at their ends, so that as they are forced between the wedge-shaped contact blocks they will take a true bearing.

As the thin leaves of the primary break are more likely to injury in case the secondary does not make a good contact and the arc is thereby transferred to the primary, there is a double path through the secondary contacts at the top of the instrument. Just above the carbons are copper contacts which act as a low-resistance shunt to the primary leaves below, opening after they do, but before the carbons separate.

The secondary break is at the top of the instrument, removing from the other parts any arcs that may tend to form. The carbons are on the end of a long arm which is forced into position by means of the wedging action of the handle and thrown out very quickly when the trigger releases it. There are thus in this breaker three paths for the current opening in the following order: (1) main copper leaves; (2) copper; and (3) carbon, where any sparking takes place.

High-Tension Westinghouse Circuit-Breaker.

This is intended to protect raising transformers and consists of three parts: (1) the circuit-breaker proper, which is placed in the high-tension circuit; (2) a tripping coil for the breaker, which is operated by a shunt circuit derived from the primary or low-tension side of the transformer which is to be protected; (3) a wattmeter relay, which closes the shunt circuit when power is reversed in the high-tension circuit, thereby tripping and opening the circuit-breaker.

The circuit-breaker will open a 10,000-volt or 20,000-volt

circuit under the most severe conditions, of excessive and lagging currents. In trials it has opened a short circuit on 20,000 volts without injurious arcing. To adapt it to open with reverse current instead of overload current, a shunt tripping coil replaces the usual series coil. It is operated from a 100-volt circuit from the low-tension side of the raising transformer which the circuit-breaker protects, and is in action only when a reversal of current occurs in the high-tension circuit.

The wattmeter relay is provided with a suitable contact device for closing the shunt circuit. When power flows in the normal direction the wattmeter disc turns against a stop which prevents motion. When power is reversed the meter disc turns in the reverse direction for the fraction of a turn and closes the shunt circuit which excites the shunt coil and trips the breaker. This relieves the torque on the meter disc, and a spring returns it to the normal position and the circuit-breaker may be reset. Series current for the wattmeter is taken from the high-tension circuit by means of a series insulating transformer, while the shunt circuit is operated from the primary of the raising transformer. The wattmeter and shunt circuits are thoroughly insulated from the high-tension circuits, making all these parts safe to handle except the circuit transmitting high-tension current.

The author believes at Niagara Falls there is a cut-out on the foregoing lines which was highly spoken of by Prof. Forbes, and which seems to combine all the advantages of the fuses and of the ordinary circuit-breaker. It can be so adjusted that it will open after any number of seconds, say one to four, giving time for the arc of one breaker to be extinguished before the others in the circuits are affected, thus localising the troubles as much as possible.

Trucks.

Trucks used in England for electric cars are generally imported from America, and are chiefly manufactured by the Peckham or the Brill Company. The main features of a good truck are: (1) lightness consistent with rigidity and strength; (2) must be thoroughly braced so as to keep stiff and square without depending on the car body, to which it must be attached with as few bolts as possible. All parts must be easy of access for repairs, and the motors and wheels easily removable.

Brakes must be sufficiently effective, easily repaired and adjustable. Journal boxes must be self-lubricating, require little attention and be dust-proof. Wheels should have the

shape of their tread well adapted to the type of rail on which they have to run.

With car bodies from 22 to 28 feet over all, carrying usually from 41 to 53 passengers, a four-wheeled truck is used. In order to get round sharp curves the wheel base is necessarily restricted from 7 feet to 5 feet 6 inches. The design of the truck to secure rigidity is on the cantilever principle, with overhanging ends and with side frames of great depth. A good example of modern truck as used in Bristol, Dublin, Cork, Dudley Coventry, Norwich, Plymouth, Bradford, Liverpool, London, etc., is the Peckham cantilever extension truck.

Where long car bodies are used bogie trucks become necessary. These trucks take rather more power on account of their extra friction due to greater number of wheels and swivel plates; as only one motor is mostly used on these bogie cars with equal wheels (see Fig. 10) only half of the total weight of the car is available for adhesion. For high speed interurban traffic with heavy cars two motors are fitted to each truck, thus utilising the whole of the available weight for traction. Where one motor is used on each truck the maximum traction principle (see Fig. 11) renders it possible to get from 60 to 70 per cent. of the total weight of car and motor available for adhesion on four of the eight wheels of a double-truck car. In these trucks the motors are suspended outside the driving axle, and the swivel pin is almost exactly over it.

Life-Guards.

The present type of life-guard, as shown in Fig. 12, is an iron barrel enclosing a net a few inches off the ground, but there is just enough clearance for a limb to be caught with unpleasant results. Some engineers say that the sudden application of the brakes will deflect the car front down, but the springs on the truck instantly react and the life-guard is up again. A better type of life-guard is really badly needed.

Motors.

The work of a tramway motor is perhaps more severe than that of any other type, as it has to stand shocks and jars while running; it is exposed to dirt and moisture, and is subject to severe strains at starting. It must be easily reversible in case of emergency without burning out. The requirements of a good motor are the following: (1) Lightness consisting with strength and simplicity, both mechanical and electrical; (2) it

must be of ample capacity in order to take overloads at starting without undue heating; (3) the starting torque must be very great. All parts must be easily accessible and easily taken to pieces; (4) it must be completely protected from dirt and moisture.

The standard type of tramway motor for 500 volts continuous current has generally four poles, single reduction gear (4·87) running in oil. The best efficiency of a motor is got at the high voltage at which the greatest amount of work is done. To minimise the losses through hysteresis, eddy-currents, and friction, and to obtain the full torque, it becomes necessary to use the greatest number of turns compatible with easy running, absence of heat and sparking.

Drum armatures are wound so that coils of different potential do not cross each other. Coils are made separately on forms and then bound down into wedge-shaped grooves cut in the face of the armature core. Foucault currents in the armature laminated discs are prevented by a black oxide obtained by heating these. The standard motor weighs about 1800 lb., and is rated at 25 horse-power.

During the last two years great efforts have been made to better the efficiency of traction motors, but it appears to remain at 85 per cent., although some makers say 92 per cent. has been closely approached.

Recent practice appears to reduce the diameter of the armature, the number of slots, and to increase the conductors per slot. The G. E. C. 800 has 105 slots and six wires per slot. G. E., 52—29 slots and twenty-four wires per slot.

The motor capacity for any given service is largely affected by conditions of track, grades, etc., so that any rules should be used with caution. The following will be found to give good results:—

$$\text{H.-P.} = \frac{T \times S}{5 \cdot 6}$$

H.-P. = Total or maximum horse-power rated on G. E. C. standard, one hour at a temperature of 75° C. (135° F.), temperature of surrounding air 25° C.

T = Weight of car in long tons.

S = Maximum speeds in miles per hour on the level, which generally equals twice the schedule speed.

Example.—12-ton car (maximum speed 24 miles) 12 miles schedule, find horse-power of motors.

$$\frac{12 \times 24}{5 \cdot 6} = 50 \text{ horse-power,}$$

or two 25 horse-power motors.

Power Consumption of Car.

The average energy required in a power-station may be taken as 0·1 K. W. hours per ton mile of schedule speed.

Example.—12-ton car at a schedule speed of 12 miles per hour.

$0{\cdot}1$ K. W. $\times$ 12 tons $\times$ 12 miles per hour $=$ $14{\cdot}4$ kilowatts.

With given stops per mile, the amount of power required will increase very rapidly with the speed beyond a certain point, and the cost per car mile will not furnish a reliable basis of comparison for the motive-power of different roads unless conditions are alike. A slight difference in the average speed, in distance between stations, on gradients or curves, may cause a considerable change in the amount of power required. The following table will give some idea as to the power used by cars weighing from 12 to 14 tons, running at the various speeds from 6 to 12 miles an hour, and averaging stops of 8 to 10 seconds per mile, on a straight level track.

Power at Trolley Wheel in Board of Trade Units.

Miles per Hour.	No. of Stops per Mile.	B.O.T. Units per Car.
6	6 to 14	·7 to 1·08
7	6 „ 13	·65 „ 1·43
8	5 „ 11	·75 „ 1·75
9	4 „ 9	·73 „ 2
10	4 „ 8	·82 „ 2·2
11	4 „ 7	·78 „ 2·04
12	3 „ 6	·73 „ 2·04

The above figures are an average according to Prof. Mengarini (Rome), General Electric Company, U.S.A., Mr. Dawson, and other authorities.

By placing meters on each car it was found, in America, on the Nashville Street Railway, that the cost of power was reduced from 35 to 40 per cent., as the consumption was from 1·75 to 1·9 kilowatt hour per car mile without meters. After their adoption it was reduced to 1·10 and 1·15 kilowatt hour per car mile. An inefficient and careless motor man would cost a company from 10 to 15 per cent. of the amount of his wages by careless use of the controller. This can only be checked by the use of a meter in each car, and at the Central station. The

difference of the two readings varies between 4 and 6 per cent. owing to the loss in the lines from the power-station. The average consumption of power on an ordinary straight level track should be about 1 kilowatt per hour per car mile, or averages 20 kilowatts per car in use, and where double motor equipments and single trucks 16 to 20 feet long are used, this figure should be less.

Bonds.

In order to keep within the Board of Trade limit, that in no part of the rail return shall the drop in volts be less than 7, it is important to pay great attention to the way the bonding is done, as the resistance of joints would make considerable difference in the drop of a line when high currents were passing. From three to four volts drop is all that is allowed in the best practice, and this is achieved by the negative booster, described by Major Cardew in his paper read before the Institute of Electrical Engineers. In England and on the Continent the troubles due to electrolysis are reduced to a practically negligible quantity compared with those experienced in America, where a larger drop is allowed. In dealing with this most important subject the author will treat bonds in the following order: Continuous Rail—Electric Welded, Cast Welded (Falk, Milwaukee). Fish Plate Joints—Edison Bond, (*a*) Cork Plastic, (*b*) Solid with Plastic Alloy, Chicago type.

Continuous Rail.

That a continuous rail is entirely feasible mechanically now admits of no dispute. It makes the best electrical bond when well constructed. Expansion does not and cannot take place longitudinally when rails are firmly embedded in paving; whatever yielding there is, it is taken up in a lateral direction and the track is not sprung out of line; the life of the rail is thus also increased.

Electric Welded.

This process in its latest development consists in making a weld from a boss on the fish-plate instead of from a flat bar as in the old system. The boss is the only portion of the bar which comes in contact with the rail, therefore all the heat is concentrated at that point (see Fig. 13). As soon as a welding heat is reached the current is cut off, a heavy pressure is exerted on the weld and artificially cooled while under pressure. The effect is exactly the same as hammering or working the steel.

A strain of 350,000 lb. did not shear off a weld made in this way.

On making a joint, a bar 1 inch by 3 inches, having three bosses, is used as shown in Fig. 13, and one bar is welded to each side of the rail web. The centre weld is made first, then the end welds. The bars, when cooling, exert a powerful force to bring the rail ends together, making a perfectly tight joint. The intimate union of steel to steel, and the increased carrying capacity due to the bars at the joint, make the joint the place of least resistance. An electrically welded track is, if properly made, of lower resistance than the rail itself. By this process the head of the rail is heated but slightly, thus avoiding the danger of annealing and softening it, which is apt to be the case where the whole rail is raised to a red heat when forming the joint. The cost of first outlay prohibits the adoption of this system in most cases.

Cast Welded Falk.

This type (Fig. 14) has been used in Norwich, Coventry and Liverpool. It consists in casting an iron sleeve round the sides and bottom of the rail joints, the rail ends being first placed firmly together. In cases where they do not absolutely touch, thin plates of steel called "shims" are driven in between the heads of the rails before casting. Before fixing the moulds, which are of cast iron, the sides and bottom of the rail are cleaned, and this is generally done with an emery wheel or a sand blast. The probable cupola is shown in Fig. 15.

The cast iron running into the iron moulds cools rapidly on the outside surface, thus causing an enormous pressure to be exerted on the metal which is still in its molten state in contact with the web and foot of the rail. As the metal is poured in from one side and comes in contact with the web or thinnest part of the rail at its greatest temperature, this part of the rail is brought to a white heat, and owing to the enormous pressure exerted on the molten cast iron, by the shrinking and cooling of the outside surface of the metal, it is practically forced into the interstices of the steel, thus not only making a thoroughly good mechanical joint, but also ensuring a good electrical one, 80 to 103 per cent. conductivity of the solid rail. The author has tested this joint extensively; its only drawback seems to be the first expense.

While carrying out these tests the author found the main switch got very hot with 460 amperes, and he found there a drop of 15 millivolts. He used some plastic alloy and amalgamated the contacts of the switch, after this the drop at

460 amperes was reduced 1·3 millivolts. He used the plastic alloy to make contact on the rails he was testing. The following table gives the results of the worst joint he tested, other readings are given in Mr. Dawson's pocket-book.

Solid. 5-foot Solid Rail.		Joint. 5-foot Rail, "Falk" Joint.		Solid. 5-foot Solid Rail.	
Amperes.	Millivolts.	Amperes.	Millivolts.	Amperes.	Millivolts.
342	17·2	344	18·9	345	17
376	19	380	21	378	19·2
460	23·1	462	25	452	23·5

Cast Welded Milwaukee.

This process is somewhat different from the Falk (see Fig. 16). A casing or jacket, formed of two L-shaped pieces of rolled steel, is placed under and at the side of the joint, and is temporarily fastened to the rails by clamps. The metal is then poured round the joint inside this jacket, after which the clamps are taken off and the jacket remains in position, giving additional strength to the cast iron which it encloses. The rivets at the end of the metal case shrink on cooling and draw the outside metal of the casting close up to the rail web, thus making an almost watertight joint. Joints of this kind have been used on exposed rails on inter-urban tracks in America, between Milwaukee and South Milwaukee. Slip joints are provided, every 500 feet, and the contraction and expansion of the track has been found to amount to about $1\frac{1}{4}$ inch per 100 feet. At the slip joints the rails are sometimes 6 inches apart. The road-bed consists of a 56 lb. T-rail, $4\frac{1}{4}$ inches high, rolled in 60 feet lengths, and laid on broken stone or gravel ballast.

Fish-Plate Joints.

The Edison bond (a), cork type plastic bond (Figs. 17 and 18) is composed of two portions; namely, a plastic alloy or putty-like metal compound which makes contact between the rail and the splice-bar or fish-plate, and a flexible, elastic cork case to hold it in position as near the end of the rail as possible. The thickness of the cork case is nearly double the distance between the web of the rail and the inner surface of the fish-

plate. It is therefore compressed about 40 per cent. when in place, and after pressure has been applied it adheres to rail and plate, completely sealing the plastic alloy. The cork case is made of a compound of cork and oxidised linseed oil. It is elastic and will maintain the seal even when the plate has loosened a quarter of an inch, but it is doubtful whether this quality will last after years of use.

The current passes from one rail (Fig. 18) through one plug to the fish-plate, then through the second plug from the plate to the next rail. Contact spots, about two inches in diameter on both rails, and fish-plates are cleared of scale and rust and treated with the Edison solid alloy, which silvers the surfaces and prevents them from rusting. This fills the surface irregularities and penetrates the metals for a perceptible distance, leaving a surface to which the plastic alloy adheres.

In these bonds of Edison type 1000 amperes per square inch contact surface can be reached without the bond heating more than the rail. The following table shows some tests which will prove of interest.

Tests made February 15 to 17, 1898, at the Power House of the Boston Elevated Railway Company, by their Electrical Engineer, Mr. Roger W. Conant.

90-lb. Rail Joint with Plastic Rail Bonds under both Fish-plates. 12 inches between centres.		90-lb. Rail Joint with two West End Type No. 0000 Copper Bonds. Rails and plates new and rail ends touching. 12 inches between centres.	
Amperes.	Millivolts.	Millivolts.	Volts with fish-plates removed and rails separated.
500	..	..	25·0
600	..	..	30·0
650	..	..	33·0
750	..	13·8	
800	..	13·8	
850	5·8	..	45·0
900	6·3	16·0	49·5
1000	..	16·6	53·0
1100	..	..	64·0
1200	..	..	70·0
1400	..	..	81·0
1500	11·8	28·4	86·0
1600	12·8	30·0	95·0
1700	..	32·5	Bonds too
2200	17·5	43·0	hot to per-
2300	18·5	45·0	mit further
2400	19·0	47·0	tests.

Major Cardew expressed doubts regarding the lasting power of this bond and of the surfaces in contact with it. The author

has found, after careful enquiries, that this bond does not deteriorate with time, as can be seen from the historic samples exhibited. Its weak point seems to be that it is liable to harden under pressure and to make a bad joint should the fish-plate get loose, but the author may be mistaken. The following type seems to eliminate the possibility of this trouble.

The Edison solid bond (*b*) is made in a different form, and consists of a solid copper strip 3 inches long, $\frac{1}{8}$th of an inch thick and $1\frac{1}{2}$ inch or more high. A cup-shaped projection is pressed at each end of it so as to give a contact against the rail web close to the end of each rail. Inside the cup is a strip of steel supporting a pair of steel springs; this steel keeps the springs from wearing into the copper. All the pieces are held together by a small iron strap or staple until the bond is applied, when the sharp web on the outside of the spring cuts it away and enters the fish-plate, thus aiding the conductivity of the bond. The metal parts of the bond are amalgamated to prevent rusting, and the contact surfaces are covered with plastic alloy. The springs are proportioned to give a pressure of 1000 lb. per square inch when the fish-plates are bolted up.

When in service the springs serve merely as distance pieces so long as the joint is tight. If the nuts loosen or the plate wears, the springs still hold the bond in contact. The use of spring lock washers is advised on track nuts to keep them fast; the spring will then take up the wear of the plate. Fixing is executed as in the former type. The lubrication afforded by the plastic alloy permits the rails to move in any vertical direction without wearing the bond metal away.

Two gangs of three bonders and six track men can work at the rate of 125 joints or 250 bonds per day for each gang. On a covered track in wet or alkaline soil, where steel is apt to rust rapidly, both the springs and the sheet steel base should be treated with a petroleum compound which will permanently protect them. This, however, will prevent the fish-plate from taking any portion of the current through the bond contacts. The following table shows the resistance of bonded rails compared with solid rails :—

	Resistance in ohms.	Smallest Area in inches.
30 feet 85-lb. unbroken rail..	·000294231	8·5
30 feet of same, including joint, with four flexible copper bonds of the best type ..	·000296348	·96
Ditto, with two Edison solid ($3'' \times 1\frac{3}{4}'' \times \frac{1}{4}''$), one under each fish-plate	·000296438	·875

Chicago Type.

This bond (Fig. 19) should be generally designed so that the current density per square inch of surface contact should not exceed 25 amperes. Care should be taken in adopting this type to have plenty of flexibility in the body of the bond itself, still keeping the terminals firm so as to allow for any vertical motion should the joint or fish-plates have any "give." The great advantages of this type over the others of similar design have been fully dealt with by other engineers. The losses due to the resistance can be divided into three, namely: (*a*) contact resistance of copper bond expanded into a hole in the web of the rail by a steel drift-pin is practically negligible; (*b*) the resistance due to gathering is also very small, and this can be got over by spreading the bond when double bonds are used, placing one on top of the web and the other lower down; (*c*) the resistance of the bond proper is brought to a minimum by using copper of 98 to 100 per cent. conductivity, and by reducing its length. With short bonds, of course, a special flexible type should be adopted. That shown at Fig. 20 is built of two solid terminals, connected by flexible strands.

Some engineers object to place the bond along the centre of the web, which is the general practice in England; they say that a torsional force is exerted on the bond, which in time will tend to get loose. They place the bond in the foot of the rail, as shown in Fig. 20. It is quite true there is only a bending strain here, but there is necessarily more movement. Summing up, the author would observe that the principal thing besides the bond-conductivity, is the lasting power of the contact surface of the bond with the rail against mechanical and heating effects, produced by the wheels passing over the joints and loosening them, and by sudden large currents inherent to electric traction.

The author desires to acknowledge his indebtedness to Mr. Philip Dawson, Mr. Harold Brown, The Westinghouse Company, The British Thompson-Houston Company, The Chloride Company, Messrs. Dick, Kerr and Co., and Mr. R. W. Blackwell, who have afforded him valuable information in the preparation of his paper, Mr. Blackwell having kindly lent him the models and apparatus.

DISCUSSION.

The CHAIRMAN said that it was his pleasing duty to propose a vote of thanks to Mr. Binyon for the paper he had just read. He was sure that the Members would agree with the author in his statement that the great development which was now taking place in working tramways electrically would fully justify his bringing the present paper before the Society. It was some little time since they had had a paper on the present interesting question, and it was of great importance that it should be brought before them from time to time in an up-to-date manner. The author had evidently taken much trouble to bring forward the subject in an exhaustive way. He had laid it before them fairly and had not dogmatised, and he had given the meeting an opportunity of seeing some interesting illustrations on the screen. They were also much indebted to him for the various models and samples which he had laid on the table, including a new form of life-guard which was certainly an important detail. The paper showed how greatly practical experience had to come into play in regulating the application of electricity to traction. If they read between the lines of the paper, or of any paper on the same subject, they would see that it was of little use for a man to be only a theorist. Practical points continually came up to modify theory or to go hand in hand with its application.

The vote of thanks was carried by acclamation.

Mr. A. J. LAWSON said that he had been a great many years connected with electric traction, and some of the latest types of locomotives rather reminded him of the first electrical locomotive that was running over the Menlo Park experimental railway in 1882. The difference was only a question of degree. In those days Edison and his associates devoted considerable time and attention to electric traction. The motor that was used was an old Z-type Edison dynamo with magnets about 7 feet in length. There was a great difference between the very compact short motor of to-day and the enormous machine that was used then. The outer form of the locomotive was of almost exactly the same design as those on the Baltimore and Ohio line, but much smaller.

There were other points he wished particularly to allude to, especially the use of batteries and motor generators for traction with polyphase generators and traction on the polyphase system. When they used motor generators in connection with polyphase generators it was very desirable for the best efficiency that they

should have batteries with automatic regulators in connection with such motor generators to get the very even pressure which had been shown on the diagrams just exhibited by the author. They might thus have a very much smaller generating set fully loaded the whole time whether direct current or multiphase, and therefore the steam consumption would be lower per kilowatt, and the coal bill on the year's work would show a considerable saving.

Mr. Binyon had dealt with the type of engine which had been used in connection with the first electric railway that he (Mr. Lawson) had acquaintance with, and the evolution in means of driving was interesting. In the early days of electric lighting they used engines of high speed running from 300 to 350 revolutions, belting direct on, and getting rid of the waste of power on the counter-shaft formerly used between slow speed engines and very high speed dynamos. Later on they made the dynamos a little larger and reduced the speed very considerably, so that they were able to put them on to the shaft of the high speed engine itself. Now they had come back to the original engine running at from 75 to 100 revolutions a minute, and they had put the dynamo on the shaft of that engine, and he thought they had done a very wise thing. It would be found a most economical arrangement from the point of view of steam consumption.

With regard to the overloading of engines where no batteries were used, he thought that was a thing which they must be designed to stand to a very large extent; 50 per cent. overloading for a short time must be expected where there was no battery. He might say that engines which he put in at Dover some years ago had successfully stood such overloading. There were two engines, and last year an accident happened to one of them. The other engine for some weeks took daily an overload of 50 per cent. for some sixteen hours per day without cessation and without accident. As to trucks, he believed that a few had been made in the north of England, but only a very few, and it showed that the manufacturers of England were in a very backward condition with regard to electric traction plant generally.

Mr. Binyon, in reading his paper, had passed over the flexible bond with the modified Chicago head. That was the best bond of all, and he was sorry the author had been obliged to pass it over in consequence of shortness of time. Strange to say, it was one of the things which were of English invention. It was patented as far back as 1895 by Mr. Edmunds of Messrs. W. J. Glover and Co. Mr. Edmunds had a previous patent for a flexible bar for winding armatures with solid ends, but he had

not at first considered its adaptation to electric traction. The necessity of getting over the loosening of short solid bonds, owing to the deflection of the ends of the rails while loads were passing over, had led to the invention of the flexible bond shown by the author.

Mr. V. Watlington said that it seemed rather hard that the motor-man should be required to operate a life-guard, to use both feet, and also to have one hand on the controller and the other on the hand-brake. He did not think it would be well to employ such guards unless the motor-men were very well trained. With regard to Mr. Lawson's remarks upon bonds, he (the speaker) might point out that flexible bonds were commonly used in America, and the patent for the best type was owned by Mr. Daniels, of the American Steel and Wire Company.

Mr. W. P. Morison said that the paper contained some very remarkable figures with regard to traffic. It seemed to him rather a marvellous fact that in London the underground railways carried so much less traffic than the omnibuses carried. Could the author inform the meeting what was his authority for the figures, and how they had been obtained? Of course, it was very easy to talk about millions; but, unless they really knew the basis of the data upon which they were calculated, such figures were rather vague.

Mr. J. Bernays said that the author had specially alluded to the question of combining lighting plant and tramway plant, and had spoken rather against the combination. The electrical authorities appeared to have decided that it was better to have the tramway plant and the lighting plant separate, because, as the author had said, the load factors of both plants seemed to rise and fall during the same hours of the day, and could not therefore balance one another, so that there would be no saving in putting the two systems together. But however that might be, it had struck him (Mr. Bernays) that, even if those two factors rose and fell together, still under any circumstances if the boilers and engines were put into one station and worked together, there must be a saving of cost which would not be obtained if they were used separately for the two powers; though he could quite understand that, owing to their different voltages, the dynamos and motors might have to be kept separate for traction and for lighting. His was only a mechanical way of looking at the matter, and perhaps the author might be able to give some reasons which would show that the keeping of the engines and boilers separate for the two uses would be a more suitable arrangement.

Mr. Perry F. Nursey said that he should like to ask the author a question with regard to the continuous rail. The author said that it was perfectly feasible mechanically, and that there was no expansion longitudinally, but that there was lateral expansion that went on equally on both sides; that was to say, when the rail was imbedded in concrete under the paving, expansion went on on both sides and did not affect the rail. He (Mr. Nursey) did not see how, if the rail expanded at all, it could expand laterally without doing some damage to the concrete or other material in which it was imbedded. On the other hand, he did not see what there was to prevent its curving in one direction or another. The effect of expansion must make itself felt either longitudinally, vertically or laterally.

With regard to the metal bonds, the author said that the molten metal was poured in, and that the outside became very rapidly cool and exerted enormous pressure upon the molten metal inside. But it struck him (Mr. Nursey) that the metal had to be poured into the mould to make the bond, and that its first contact was made with the two ends of the rail and their surroundings, whatever it was that held them together, and therefore the probability was that the rail would chill the metal first, and that the outside contraction would not have the great effect in forcing the metal into all the cracks and crevices of the rail-ends that the author claimed. The author said that a white heat was set up, but he (Mr. Nursey) did not see how a white heat, or anything approaching it, could be set up if the metal was run from a cupola, unless the surfaces of the rail were heated up first.

Mr. F. E. Skinner said that he should like to call the attention of the meeting to a special insulating sleeve or bush used in connection with the trolley system. Mr. R. C. Quin, the electrical engineer of the corporation tramways at Blackpool, had experienced considerable difficulty in maintaining the insulation of the trolley wire, earth leakage causing frequent breaks down and interruptions in the traffic, and in some cases causing much damage to the poles themselves. After some experiments, Mr. Quin decided to try bushes made of woodite, a well-known insulating material. Two types of these bushes were at present in use at Blackpool, and examples of them were on the table. The moulded bush was the pattern originally designed by Mr. Quin. The other one was a modified form, the alterations being made to obviate the necessity for a mould. The results of use were equally satisfactory for both patterns, and had proved so successful that Mr. Quin had decided to

adopt those bushes on the tramways of which he was consulting engineer.

Mr. Binyon, in replying upon the discussion, said that with regard to the flexible bonds, personally, he did not think they would last as long as other bonds, because there was always a tendency on the part of the metal to crystallise. That happened in a bond just the same as in ordinary fuses. There were several types of bond which would illustrate what he meant. The circular section, for some reason or other, gave a far better result than the parallelogram section or the section with parallel sides. The flat ribs were supposed to take up all the vibration, but it was found that they always snapped off, and the middle was found to be highly crystalline.

He quite agreed with Mr. Watlington that the motor-man had his hands too full to attend to the life-guards; but in that case the model on the table would not be very much better than the ordinary life-guard which was illustrated in the paper. The only advantage was that it would be in front of the car instead of underneath it.

Mr. Morison had asked where the figures relating to London traffic had been obtained.

Mr. Morison said that Mr. Binyon had taken the underground railways; but the tramways were all overground, and the omnibuses were all overground.

Mr. Binyon said that the figures were got from the total number of tickets issued at the various railway stations and by the various tramway companies in London.

In America, the working expenses of traction had been thoroughly investigated, and it had been found that the cost per car-mile when using electricity was $1\frac{1}{4}d.$ less than that of steam. If electric traction was adopted on the suburban railways in London, there would be a saving of cost, even if the traffic did not increase. But traffic was increased by electric traction, and that was an important point. Electric traction gave a higher speed between the local stations than an ordinary steam locomotive, and the time between the stations was reduced. A maximum speed of about fifty or sixty miles could be obtained by electric traction. A person living near Sloane Square would highly appreciate getting to the Mansion House in ten minutes, or a quarter of an hour less than the time now occupied on the District line.

Mr. Morison said he thought the introduction of electricity on the Underground would be a great improvement.

Mr. Binyon said that in America electricity was used overground, and it effected a considerable saving. Germany and France had railways working by electricity.

As to the combination of traction and lighting, it was perfectly true, as Mr. Bernays had said, that the same steam boilers could be used for both purposes. That was the case, and there was no reason whatever why the same boilers should not be used. Personally, he was in favour of the combination on a large scale; but the dynamos should be separate, because the fluctuations were so large; and the switch-boards should be entirely distinct.

Mr. Nursey had spoken about the continuous rail. The first experiments on that point were carried out in America. The rails were entirely imbedded right along, and the ends of the rails were opposite each other. There were thermometers underground and above ground, and the temperatures were taken, and the expansion of the rails was taken. It was found that the expansion was a practically negligible quantity. As to lateral expansion, the head of the rail would expand because the head was not imbedded in the earth. The road-bed in England was far better than in America, and therefore there was not so much heard about the trouble at the joint as in America.

Mr. NURSEY asked what the length of the rail was which was experimented with.

Mr. BINYON said that the length was about 100 feet.

With regard to the casting of the joints, Mr. Nursey was perfectly right in saying that there was a chill put on the metal as it came into the mould. On the table there was a sample which would show that result. The actual welding only took place in the centre. When the joint was broken off, the rail broke away with it. The electric contact practically took about 3½ square inches. To obviate the effect of the chill the rail was heated before the joint was formed. Blow-lamps were used, and the rail was made very nearly red hot. There was, of course, a disadvantage in this process, as the rail became soft and lost some of its carbon.

With regard to the woodite bushes which Mr. Skinner had described, he would like to ask that gentleman what the cost of them was.

Mr. SKINNER said that they were 18*s.* each.

Mr. BINYON said that he thought that was a very high price to pay just to prevent leakage.

Mr. SKINNER said that leakage was a very important point.

Mr. BINYON said that it was an important point; but there was double insulation, and it seemed to him that the appliance which Mr. Skinner had spoken of was not quite necessary.

Mr. SKINNER said that at Blackpool it was difficult to maintain insulation at all.

Mr. Binyon said that that was probably due to the salt water. There were several points which he had to pass over in reading his paper. He should like to say that he believed that it would not be many years before electric traction would be a very great factor in the traffic of London. Probably it would not be used in the main thoroughfares, but he believed that it would be readily adopted in the outskirts of the metropolis.

Fig. 1.

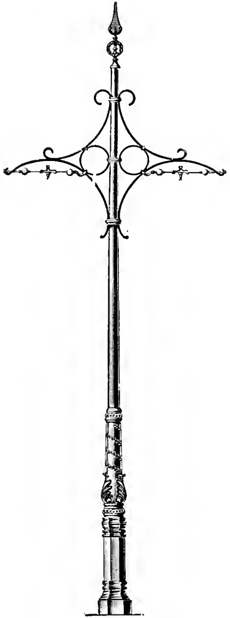


Fig. 2.

Fig. 3.

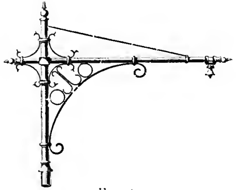


Fig. 4.

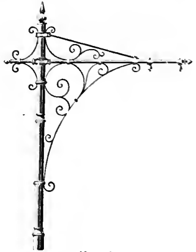


Fig. 5.

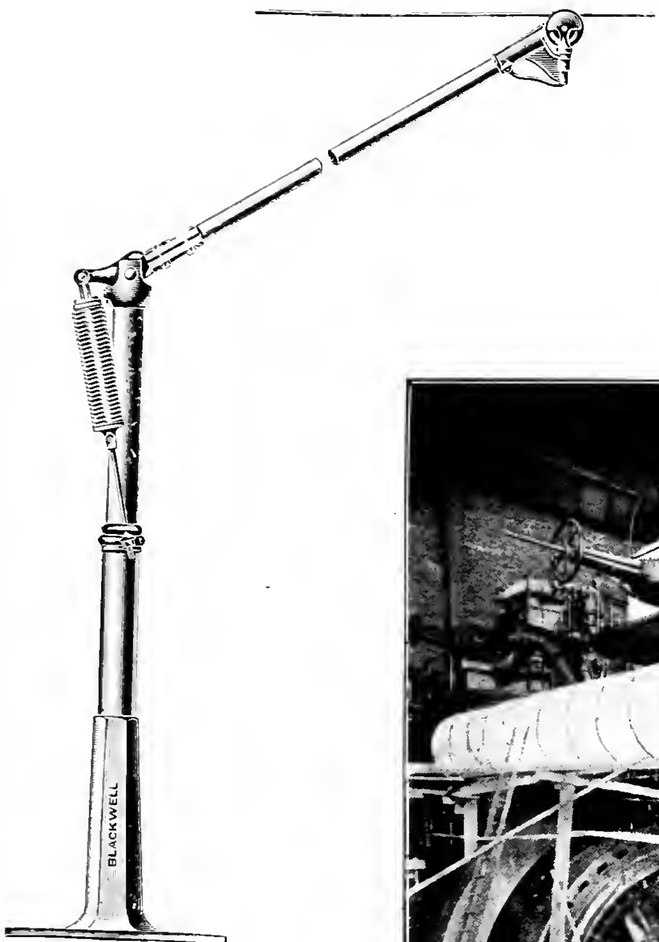


FIG. 6.

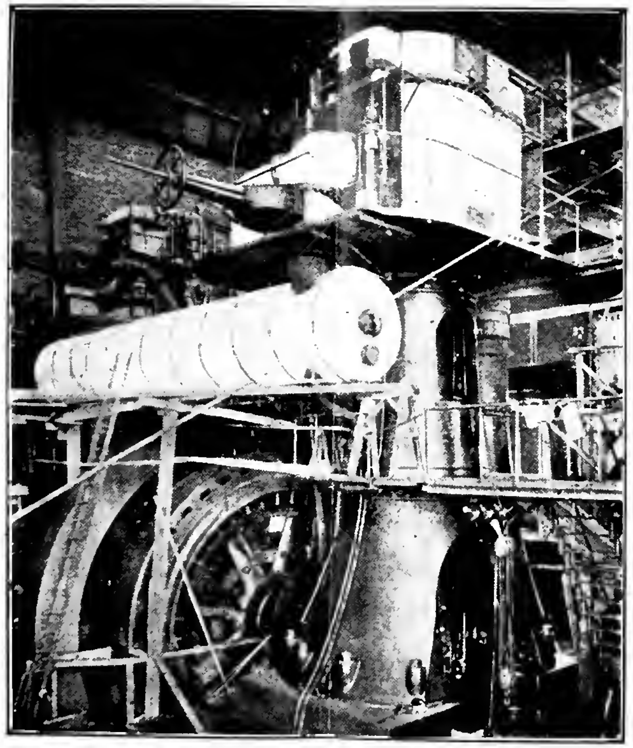


FIG. 7.

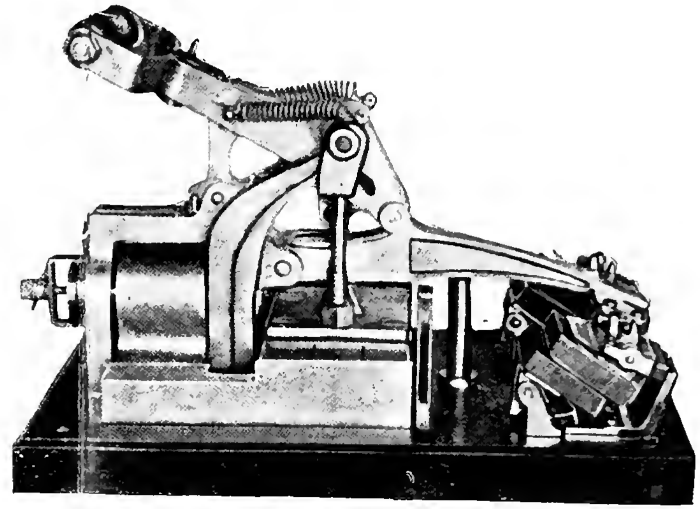


FIG. 8.

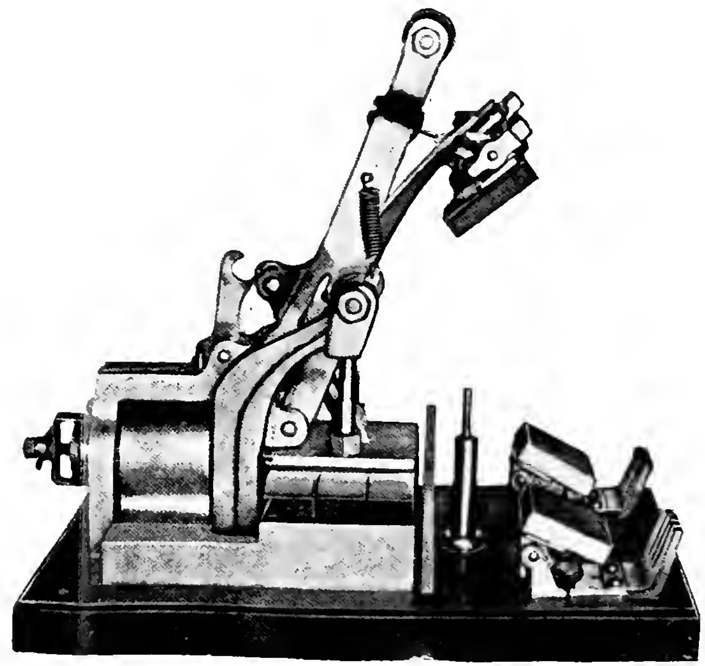


FIG. 9.

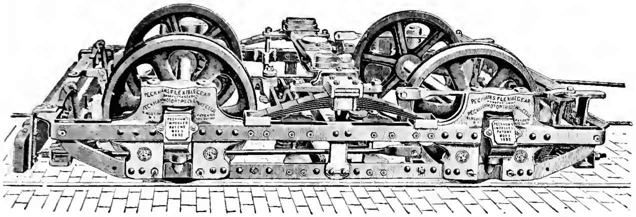


Fig. 10.

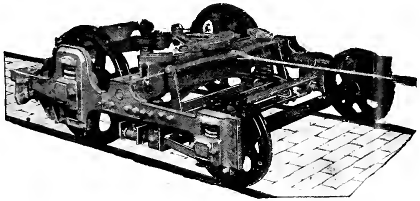


Fig. 11.

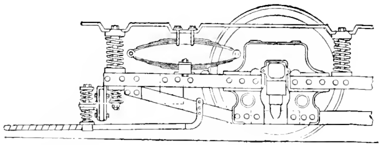


Fig. 12.

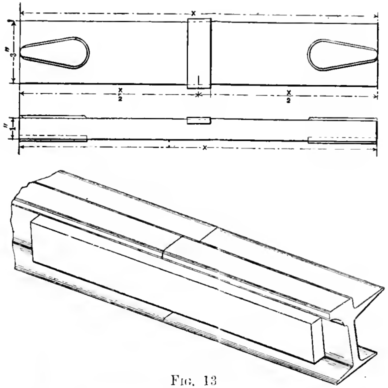


Fig. 13

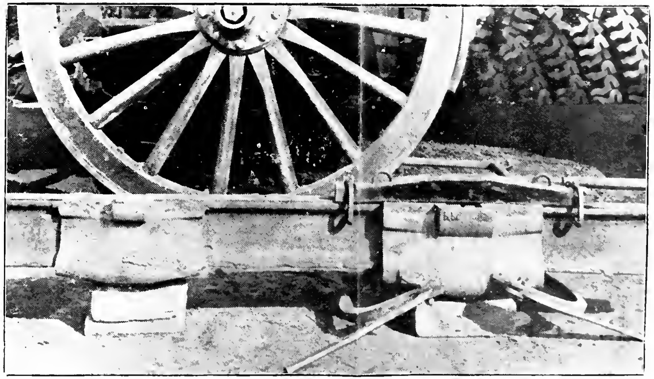


Fig. 14.

Fig. 16.

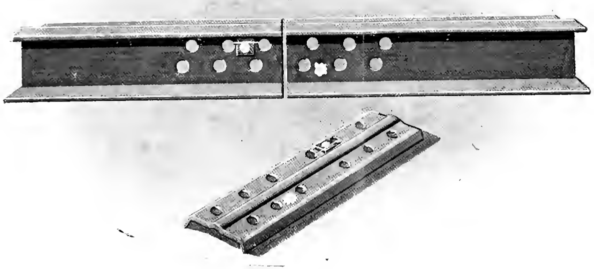


Fig. 17.

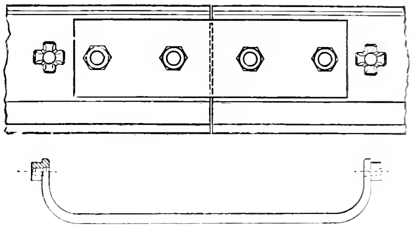


Fig. 19.

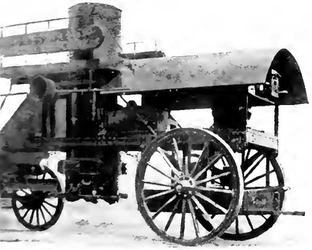


Fig. 15.

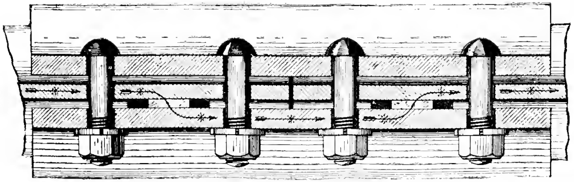


Fig. 18.

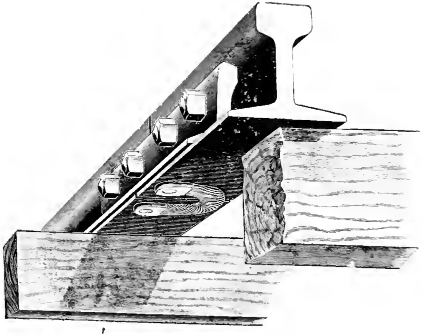


Fig. 20

VACATION VISITS.

The usual Vacation Visits were made during the summer and autumn of 1900. They were three in number, and the first, on June 20, was to the Thames Ironworks Shipbuilding and Engineering Company's Works, Orchard Yard, Blackwall. The second visit, on July 18, was to the School of Gunnery, Shoeburyness. The third visit, on September 26, was to the works of the Gas Light and Coke Company, at Beckton.

The following are general descriptions of the several works visited.

The Thames Ironworks Shipbuilding and Engineering Establishment.

These works have a frontage on the river Thames and extend some distance up Bow Creek. They are the growth of more than half a century, and now cover an area of some thirty acres on the Essex side and three acres on the Middlesex side of the Creek. They are divided into four departments, of which the shipbuilding is the oldest and most important. The other departments are the civil engineering, the electrical engineering, and the dry docks. The engineering department has lately been moved across the river to the works formerly occupied by Messrs. John Penn and Sons, whose business the Company took over in 1899.

Shipbuilding.—The Orchard Yard witnessed the commencement of iron shipbuilding in England, which was inaugurated there about the year 1835 by Messrs. Ditchburn and Mare, the then proprietors of the works. Since that time a large number of vessels, including some 100 vessels of war for the British and foreign Governments, have been constructed, ranging from battleships of 15,000 tons downwards, and having a total displacement tonnage of some 350,000 tons.

To the Thames Ironworks Company belongs the honour and credit of having built H.M.S. *Warrior*, the first sea-going iron armour-clad in the British Navy. The constructive methods and details of a new departure in warship building were first worked out at this yard, at which the change from wood to

iron in shipbuilding generally had previously been initiated. The success of the *Warrior* led to work for foreign countries, the German, Russian, Austrian, Spanish, Turkish, Portuguese and Greek Governments having placed orders with this company, with the result that the fleets of Europe have been largely launched from their slips at Blackwall. For the last eighteen years these works have been mainly engaged in constructing vessels of war for Her Majesty's fleet, commencing in October 1882 with the construction of the *Benbow* battleship, an improved *Collingwood* or *Admiral* class. On this vessel were mounted two 110-ton guns, the only guns of this weight in the Navy at that date. The Thames Ironworks Company, however, are not only constructors of ships of war, they are also builders of every type of craft.

In the shipbuilding department the special objects of interest to the visitors were H.M.S. *Duncan* and *Cornwallis*, first class armoured battleships which are in course of construction, the following being their dimensions:—

Length	405 feet 0 inches.
Breadth	75 „ 6 „
Draught of water	26 „ 6 „
Displacement	14,000 tons.
I.H.P.	18,000
Speed	20 knots.

The machinery of 18,000 I.H.P., for these vessels, together with a similar set for H.M.S. *Albemarle*, is being constructed at the company's engineering works at Greenwich, recently taken over from Messrs. John Penn and Sons. In the boat-building sheds the visitors saw a number of lifeboats being built for the Royal National Lifeboat Institution, with whom the company has a contract for the construction and repair of all their boats. In the shops connected with the shipbuilding department the visitors found a complete equipment of first class machines and tools of the most modern design and construction. Among the most interesting were pneumatic tools for caulking, chipping, etc., and portable electric drills, which were seen at work on the battleships. These drills are a speciality of the company.

Civil Engineering.—The civil engineering department is situated at the northern extremity of the company's premises, adjoining the foundry and saw-mills. On the eastern side it has frontage to the Great Eastern Railway, with a siding 430 feet in length, and on its western side a river frontage and barge berths, 300 feet long. It comprises a suite of offices and stores, large press shed, upper and lower machine and fitting shops, mould loft and smithy, as well as extensive erecting

space under travellers. It is also well served all round with a 3-feet gauge railway, upon which locomotive cranes pass the material to and from the various shops.

In the shops all classes of constructional iron and steel work are manufactured, and amongst other items, the visitors were enabled to inspect the following: Girder work for the Tarkwa Railway, Gold Coast; bridge spans of various sizes for the Norwegian Trunk Railway; 30-feet spans for the East Indian Railway Company; spans of various sizes for the Burma Railways Company; spans of various sizes for the Bengal-Nagpur Railway Company; roofing and steel constructional work of various descriptions; and steel freezing cells for the Atlas Company of Copenhagen.

The machinery is of the most modern type, and includes presses capable of shearing $1\frac{1}{2}$-inch steel plate and punching $1\frac{1}{2}$ inch diameter holes in the same; croppers for 6 inches by 6 inches by 1 inch angle iron; plate milling machine with 100 feet bed, to mill both edges of two stacks of plates simultaneously, and straightening presses for rolled steel girders up to 16 inches deep. There are also drilling and milling machines driven by electric power; planing, punching and shearing machines, cold saws, angle straightening machines, electric travellers, hydraulic power riveters, hydraulic presses and other tools.

The floor space of the smithy measures 4500, that of the machine shops 6300, that of the mould loft 4100, and that of the covered press shed 15,300 superficial feet. The yard is served by three travellers working upon steel gantries, each 50 feet in clear by 250 feet long, two travellers of thirty and five tons respectively being worked by steam, while a third of five tons capacity is electrically driven. These travellers are used for transferring material to and from the yard and barges in the river or the trucks on the railway siding. The whole of the yard, the workshops and the offices are electrically lighted.

Electrical Engineering.—The electrical engineering department undertakes electric light and power installations, and has carried out the electrical equipment of the vessels built by the company. Here the visitors witnessed the production of general electrical machinery and apparatus, including dynamos, motors, electric fans, portable electrical drilling machines, searchlight projectors, switches and switchboards. In consequence of the transference of the marine engineering department to the newly acquired works at Greenwich, the present machine shops at the Orchard Yard will be devoted almost entirely to electrical manufactures, and the resources of the electrical engineer-

ing department will be greatly augmented. Contracts at present in hand include:—Dynamos and electric installations for the Poplar Union, the Borough of West Ham, Barking electric tramways, and electric pumps for the Central London Railway.

A central generating station has been established in the works for supplying current for consumption in the several departments. The installation consists of three locomotive and two gunboat boilers, the latter of the company's manufacture, aggregating 600 I.H.P. There are nine sets of engines and dynamos aggregating 350 kw., three sets having been built by the Thames Ironworks. Distribution of current is effected on the three-wire system, the main cables to the distributing centres being of vulcanised indiarubber insulation, laid in cast-iron pipes underground. The electric current generated is chiefly used for lighting purposes, but is also supplied to the motors employed in the works for driving machinery. The use of electricity for power purposes is in course of extension.

The electro-galvanising of Belleville and other boiler tubes and steam pipes was seen at the plant adjoining the boat-building sheds. This galvanising plant is the largest in the kingdom. Current for plating is obtained by transformation from the electric lighting mains.

Dry Docks.—The dry docks belonging to the company are perhaps the finest on the river Thames. They were built some thirty years ago, at a cost exceeding a quarter of a million sterling. The large dock has 22 feet of water over the sill, with pumping-engine and boiler shop, and will accommodate vessels of the largest capacity. The small dock has 19 feet over the sill. A smart piece of work was carried out at these docks some six years ago, when the *Invicta*, built for the London, Chatham and Dover Railway Company by this company, was brought to London, after being stranded for seven days upon the Calais sands. The vessel was carefully shored, and the whole of the bottom was taken out and replaced in the course of four weeks, working day and night. On the quay side of this department are sheer legs to lift 80 tons.

The School of Gunnery, Shoeburyness.

At the School of Gunnery and Experimental Ranges at Shoeburyness the Members were received by Colonel J. F. Bally, R.A., Commandant; Colonel H. Barron, R.A.; Major T. D. Inglis, R.A., Brigade Major; and Major Lowe, R.A.; by whom, and by the officers of their staff, they were first conducted

to the instructional portion of the school, where they witnessed some excellent practice from a siege battery of two 6·6-inch muzzle-loading howitzers at a revetment wall. At the old gantrey, practice was carried out with 6 and 12-pounder quick-firing guns against a moving target, the practice being illustrative of resistance to a torpedo-boat attack. The target was moved to and fro in the sea at a speed of 19 miles an hour, and the result of the practice was 6 hits out of 21 rounds. The visitors were then entertained at luncheon at the Royal Artillery mess by Colonel Bally and the officers, after which they were conducted by Major Lowe to the new experimental ranges, where they witnessed the testing of time fuses by shell fire from a 12-pounder breech-loading field gun. This gun was afterwards fired for rapidity, when 10 rounds of shell were got off in 1½ minute. The final practice was the proving of fuses with the 4·7-inch gun. The visit was concluded by an inspection of some perforated armour plates, and of various departments of the instructional section of the School of Gunnery.

The Beckton Gas-Works.

The works of the Gas Light and Coke Company at Beckton, which occupy close upon 300 acres of land, are situate on the Thames about a mile below Woolwich, and constitute the largest manufacturing works of the company, producing about one-half of the gas supplied by it. For this purpose, from 3300 to 5500 hands are employed, according to the time of year. The coal is brought alongside two T-shaped piers by steam colliers, and loaded, by the aid of hydraulic cranes, into wagons. After having been weighed, the wagons are made up into trains, which are drawn by locomotives along an elevated railway to the coal stores of the retort houses, or to any other part of the works, as may be required. Coal is also stored in spaces provided under the elevated railway. There are 14 retort houses, containing in all 8404 retorts. About half the carbonising plant is operated by machinery: hydraulic power, compressed air, and power transmitted by ropes being employed. The stoking of the retorts is conducted on staging, the space beneath which is utilised for tending the furnaces and manipulating the coke, the bulk of which is shipped into sailing vessels at the wharf. On leaving the retorts the gas is cooled and passed through the ammonia-extracting and other purifying plant. It is then passed through the meter, measured, and stored in the gasholders, of which there are nine at the Beckton Works, having a total capacity of 19 million cubic feet. There are also

holders at other stations for the storage of gas produced at Beckton, to the extent of 35 million cubic feet. From Beckton the gas is pumped under pressure to the storage stations in various parts of the metropolis. The output of gas at Beckton is about 50 million cubic feet per day, besides 8½ million cubic feet of oil gas. The total quantity of coal carbonised at these works is 1,150,000 tons per annum, and of oil 6,000,000 gallons. The works include a foundry, smiths', fitters' and carpenters' shops, stores, etc., and every description of plant necessary for the repair and maintenance of the establishment generally.

October 1st, 1900.

HENRY O'CONNOR, PRESIDENT, IN THE CHAIR.

PAPER-MAKING MACHINERY.*

BY ROBERT HENDERSON.

INTRODUCTORY.

WITHIN the last few years the stress of foreign competition, due, in very large measure, to the development of wood pulp as a suitable fibre for paper-making, has led to great improvements in the design and construction of machines for manufacturing paper. The mills of America, Scandinavia and Germany, situated in the midst of vast forests, with plentiful supplies of water power, and in the latter countries, at any rate, with abundance of cheap labour at hand, are in the most favourable position for obtaining and working the raw material, and are able to produce saleable paper from wood pulp, and to export it to this country at very low prices.

To meet this competition, British paper-makers have had to look both to their methods and machinery, so as to get the maximum of output with the minimum of labour. Probably the greatest improvements have been made in the paper-making machine itself, though the preparatory plant and the general arrangement of factories have by no means been neglected. The general tendency has been to increase the width of the machines, so that, while a dozen years ago a paper-making machine capable of producing a finished web 90 inches broad was considered a wide machine, there have now been built in this country several machines which can turn out a web between 11 and 12 feet broad, and one at least is running in Scotland, capable of producing a reel 12 feet 6 inches in width. The speed has also gradually crept up until, although perhaps not attaining quite such high speeds as are reported from America, 360 feet per minute is being run daily and continuously, and even higher speeds have been reached.

* A Society's Premium was awarded to the Author for this paper.

The Mill.

In laying out a new mill, the first and most important consideration is the water supply. This must be abundant and as pure as possible. When it is considered that the amount required for the processes of manufacture alone may be from 100,000 to 180,000 gallons per ton of paper produced, the importance of this will be realised. It is for this reason that many paper mills are found in situations which for most kinds of factories would be considered far from advantageous. The proximity of a river has of course the advantage of providing a cheap source of power, and also where there are no Pollution Acts in force, the river is a convenient means of carrying off the waste products.

The nature and quality of the paper to be made are the main factors in determining the machinery to be employed. Thus a mill to produce cheap news paper requires special facilities for rapidly dealing with large quantities of wood pulp and "broke" paper; a paper-making machine capable of running a wide web at the highest speeds, and arranged so as to be easily handled in all operations—quantity of output being in this case of the highest importance. On the other hand, a mill to produce a high-class printing or writing paper, will in general be slower in its movements. The amount of the mill's output will of course be as great as is possible with the machinery at command, but the greatest attention has to be paid during each operation to ensure that the quality is maintained. The machinery for such a mill has to be adapted for dealing with rags or esparto, or materials which give a long and strong fibre. Whiteness or colour being of great importance, the raw material must be subjected to the most careful cleaning. It must be treated in smaller quantities in order that it may be subjected to more careful supervision. The process of reducing the raw material to pulp involves boiling, washing, bleaching and beating. Many of the vessels and pipes through which the pulp passes must be copper-lined, or made of copper, so that no iron rust may discolour it. The paper-making machine is only required to run at a moderate speed, and has to be provided with arrangements for giving the paper a fine surface or a high glaze. From the machine the paper passes to the finishing-house, and is there run through heavy glazing calenders. It is then cut into sheets by the cutting machine, and finally examined, sheet by sheet, before being packed for sale.

Nearly every paper-maker has his own method of producing the particular paper he makes, and his own ideas of the

machinery to be employed in the process, so that it is safe to say that there are no two mills, nor even two paper-making machines, exactly alike. It will therefore be readily understood that the author can only treat, in a general way, of a few of the machines in use. To give a general, and at the same time a fairly comprehensive idea of the nature of paper-making machinery, the author has considered it best to treat of the machinery employed in the production of a high-class paper, and to endeavour to point out the differences which are made in the machines and the operations involved for treating the different fibres. At the same time he wishes to say that any remarks on the processes are made entirely from the engineer's point of view, as he does not pretend to have sufficient knowledge of the paper-maker's art to warrant him in speaking of it with any authority.

General Plan of Mill.

For such a paper, rags and esparto will be the chief materials used, and a general plan of a mill for dealing with these materials is shown in Figs. 1 and 2. The processes involved will be—sorting, cutting, dusting, boiling, pulping (which comprises, first: washing, breaking, bleaching and pressing—secondly: beating), making into paper on the paper-making machine, calendering and cutting. The illustration does not represent an actual mill, but is to be regarded as a design showing a convenient arrangement of buildings to permit of the processes following in proper succession, without any unnecessary time being spent in travelling from one part of the mill to another, or of returning again over the same ground. The factory is so arranged, that the materials shall gravitate as far as possible, the raw materials entering the mill from the railway siding, and being lifted to the top floor, and thereafter working their way downwards through the mill until they are delivered again, as finished paper, to the same railway siding. Such an arrangement also permits of easy extension, as a new paper-making machine and all the preparatory and finishing plant in connection with it, can be put down alongside, without in any way disturbing the work in the existing factory.

Rag-Cutters.

Beginning with the rags: these are first carefully sorted out and given a preliminary dusting. They then pass into the cutting room, where they are cut into pieces about 4 inches square. For the highest class of papers they are still cut by

hand, as this method, although expensive, permits of a supervision and selection of the rags unattainable when a machine is used. Rag-cutting machines are also credited with tearing and damaging the fibres to some extent when used for the finer qualities of rags, but with the coarser qualities and such material as ropes or canvas, this disadvantage is not apparent, and machines are much employed. The older form of machine consists of a drum, carrying three knives fixed at an angle across its periphery revolving in a frame which carries a dead knife. A felt carries the rags forward to the dead knife, and a feed roll, worked by a treadle, regulates the supply; when cut the rags fall upon a second felt which conveys them to the duster. This type of machine has now largely given place to those which have vertical knives worked by a crank and connecting rod, of which there are several varieties.

The Willow and Duster.

From the cutter the rags pass to the willow and duster, shown in Fig. 3. The willow is placed in front of the duster proper and consists of two drums, each provided with several rows of wrought-iron spikes which interlace with each other by the revolution of the drums, and with similar rows of spikes placed in the casing. The drums are driven at 260 revolutions per minute. The rags are fed in by a travelling felt, and are caught and knocked about by the spikes, which thus loosen and beat out the dirt. A cam motion, at suitable intervals, raises a door and admits a certain quantity of rags into the duster. This consists of a cylinder of wirework of $\frac{1}{4}$-inch mesh, about 4 feet in diameter by 14 feet long, placed on a slight incline. The cylinder makes about 15 revolutions per minute. Spikes are also placed round the inside of the cylinder, which lift and toss the rags as it revolves, the dust passing through the meshes into the wood casing surrounding the cylinder. The rags, assisted by the revolution and the incline of the drum, find their way out at the open end, while the dust is withdrawn from the casing by a fan.

The Grass Duster.

The grass duster is in effect a combination of the willow and duster for rags just described. This machine has a conical drum, usually placed horizontally, and carrying several rows of spikes, which pass through the spaces of similar rows placed in the conical cover. The bottom of this conical casing is of open wirework. The whole underpart is again enclosed

in an outer casing (the sides of which are removed in the illustration at Fig. 4), and into this the suction trunk of an exhausting fan is led. The grass is delivered into a hopper at the small end of the cone, and is caught by the spikes of the revolving drum. The speed of this drum is about 200 revolutions per minute. The loosened dust finds its way through the wires at the bottom of the inner casing, into the outer casing, whence the light particles are withdrawn by the fan, while the grass, by the rotary motion, the slope and the increasing diameter of the cone, is guided to the large outlet end and is removed by a revolving rake. If the duster is placed on a lower level than the boiler mouths, this rake delivers to a grass elevator, an apparatus similar in design to that often used for stacking straw.

Rag and Fibre Boilers.

Both rags and grasses pass from the dusters to the boilers, in which they are boiled in an alkaline solution under steam pressure. The object of the boiling, whatever be the material, is to separate the cellulose or paper-making material from the substances combined with it which are not available for the manufacture of paper. The alkali employed is usually caustic soda. In the case of rags, there is often a considerable amount of grease, colouring matter and dirt which have to be got rid of. The alkali combines with the grease to form a soap, and the boiling action, aided by this, removes the grease and loosens the dirt, etc. which would hinder the subsequent bleaching process. The caustic soda has also the effect of softening the fibres. An analysis of esparto grass shows that it contains from 45 to 48 per cent. of cellulose, the remainder consisting of resinous, gummy and silicious matter which is useless for paper-making. These substances have to be dissolved or broken up by the boiling.

Rotary Rag Boilers.

Boilers for rags are either rotary or stationary, the rotary action being considered to ensure a better mixture of the caustic liquor with the rags, and to aid by the shaking or tumbling action in loosening the dirt. The rotary motion also provides a convenient means of emptying the boiler. They are made either spherical or cylindrical (see Figs. 5 and 6). Spherical boilers are usually from 8 to 9 feet in diameter, while the cylindrical type are about 7 feet in diameter, and have been made as long as 25 feet: 16 to 18 feet is a

common length. They are hung on trunnions of cast steel, and make about one revolution in three minutes. Steam is admitted through one of the trunnions, and the water is run in through the other. A large door, or in the case of cylindrical boilers two doors, 30 to 33 inches diameter, are provided for charging and emptying the boiler. Opposite the doors is a cock for running off the spent liquor, a perforated drainer plate covering the entrance to the cock. Perforated drainer plates are also fixed inside the boiler, over the steam and water inlets. In cylindrical boilers, to ensure a better distribution of the steam, a three-way cock is fixed inside at the steam trunnion, as shown in Fig. 5 at *a*. The plug of the cock is stationary, and the barrel being fixed to the boiler shell revolves about it. Tubes are taken away from each branch of the cock so as to divide the length of the boiler into three. A small blow-off cock is also fixed on the shell at *b*, operated by a star-wheel so as to automatically open and close at a convenient part of the revolution of the boiler.

Stationary Fibre Boilers.

For the finer grades of rags stationary boilers are also used, and these are universally employed for boiling esparto. The older stationary rag boilers were built of cast-iron plates, and worked with a pressure of from 5 to 10 lb. per square inch; but for esparto boiling, they are now built of steel and work at a pressure of from 40 to 50 lb. per square inch. Many forms are in use—one of the best, known as Sinclair's patent, being shown in Figs. 7 and 8. Fig. 7 is a vertical section through the boiler; Fig. 8 is a sectional plan; while Figs. 9 and 10 show the arrangement of the various pipes.

This boiler is 9 feet diameter by 9 feet deep, and holds from $2\frac{1}{2}$ to 3 tons of esparto. It is charged from a door at the top, a similar door being provided at the bottom, on the side, for emptying. A perforated diaphragm plate extends across the top, and a similar plate is fixed at the bottom. Between these two diaphragm plates, there are fixed to the shell of the boiler two vertical D-shaped pipes known as the vomit pipes. On the top of the boiler is a vertical stand pipe, with branches for connecting the blow-off, lye and water pipes. A small cock is also fixed to the top of this pipe for letting off the air. A pipe is fixed to the bottom of the boiler, one branch of which admits the steam, while the other is used for running off the spent lye.

The boiler is charged by putting in the grass and running in the water and lye at the same time, or the caustic soda is

often introduced in lumps with the grass. The charging door is then bolted down and the steam turned on. The circulation is established by the hot liquor rising through the vomit pipes and descending through the mass of the grass, being spread over the whole upper surface by the perforated diaphragm at the top. The boiling with this apparatus can be accomplished in two hours. The spent lye is then run off to the supply tanks of a multiple-effect evaporator for recovery of the soda. Water which has been heated by the blow-off steam is then run in from a tank overhead, in order to free the grass from the fatty substances which may still remain. This water having been allowed to remain for some time in the boiler, is also run off to the evaporator. The boiler is then filled up with clean cold water, in which the grass lies until it is ready to be withdrawn, when this water is pumped up to the tank to be heated and used for the first water of the next boiling; or a later method is to pump the water through the grass in the closed boiler to the tank overhead, this method being said to give very good results. The special feature of the Sinclair boiler lies in the perforated spreading plate, which, by distributing the lye, ensures both more equal and rapid boiling than can be accomplished by the older form of boiler provided with one central vomiting pipe, with a baffle or spreading plate on the top.

Washing and Breaking Engines.

On being taken from the boilers, the fibre is subjected to an overhaul, to remove any foreign matter which may have escaped notice in the cutting room. It is then sent to the washing and breaking engines. This machine, known as the Hollander, from the fact that the credit of its invention is due to the Dutch, is shown in Figs. 11, 12, 13 and 14.

The engine consists of a tank or vat with semicircular ends, divided longitudinally by a midfeather *a*, which usually extends the whole distance between the centres of the ends or even a little further. The bottom of this vat is very carefully curved, sharp corners being avoided, to ensure that the engine shall circulate or travel properly and that there shall be no lodgment of the material. Transversely at the centre of the engine in one of the two channels formed by the midfeather, the roll *b* is placed. This is generally a hollow cast-iron cylinder, mounted on a heavy steel shaft, and having, lengthwise, a number of grooves cast around its circumference. Into these grooves steel knives or bars are fitted. In engines for washing esparto, which requires but little breaking, these bars are placed in

groups of two, while in rag breakers they may be in groups of three. The bars in each group are pitched from $1\frac{1}{2}$ to $1\frac{3}{4}$ inches apart, while the grooves or spaces are so pitched that there is a space of from $2\frac{1}{4}$ to $2\frac{3}{4}$ inches between the clumps of bars. They themselves are usually made about 5 inches broad by $\frac{3}{8}$ inch in thickness and bevelled away from the edge for $1\frac{3}{4}$ inch. They are firmly wedged into position with hardwood slips and secured by wrought-iron hoops, shrunk into recesses provided for them in the ends of the bars. These rolls are made from 3 feet to 4 feet 6 inches in diameter for large esparto washing engines, carrying over eighty bars and weighing with their shafts from $3\frac{1}{2}$ to 4 tons.

Under the centre of the roll, a recess *c* is cast in the bottom of the engine called the den. Into this a cast-iron box is fitted which carries the plate *d*. The plate consists of a number of bars similar to those in the roll, of varying breadth, arranged so that their cutting edges form a segment of a circle of the same radius as the roll. The bars of the plate are usually made about $\frac{1}{4}$-inch thick and separated from each other by dividers of zinc, about $\frac{3}{16}$ inch thick, so that the pitch is $\frac{7}{16}$ of an inch. They are held together by bolts and firmly wedged with wood into the plate box. The whole plate is bent or elbowed slightly at the centre, usually $1\frac{1}{4}$ inch, so that the roll, when revolving upon it, has a shearing action.

The bottom of the engine has a slight rise to the plate, and behind it is carried up round the roll to a point about 4 inches below the centre. From this point it slopes down in a spiral curve to the level of the bottom. This part is called the backfall. An outlet valve *e* for the pulp, and a valve *f*, for washing out, are placed in the bottom of the engine. At the curved end behind the backfall, the drum washer *g* works. This is simply a lifting wheel or drum covered with brass wire gauze having about 66 meshes to the inch, fixed upon a honeycombed punched brass or copper backing, and provided with five or six lifting buckets of sheet copper. The buckets discharge through a central spout which runs to a passage cast down the outside of the engine or to a separate run-off pipe. The drum-washer is driven from the end of the roll spindle by a belt and spur gear, and means are provided for raising and lowering it. A water valve with an overflow cistern *h* is fixed at the breast end of the engine. It is common, in rag-breakers, to cast a recess across the roll channel in the breast, or rising slope to the plate. This recess is covered with a perforated plate, and communicates with a cock fixed on the front of the engine. It is called the sand-trap, and is shown at *k* in Figs. 11 and 14. As its name indicates, it is for collecting sand, grit and such like impurities. The per-

forated plate is sometimes provided with recesses to catch buttons, which may have escaped the picker, and a large sand-trap is frequently placed in the channel behind the roll.

The upper part of the roll is provided with a cover to prevent splashing, and the bearings are carried on levers or wedges or suspended on screws, so that the roll can be raised or lowered to give the desired bite on the plate. The roll is driven by a pulley from 4 feet to 5 feet in diameter, carrying a belt 10 inches to 12 inches in width, and revolves at a speed of from 1400 to 1600 feet per minute at the tips of the bars.

For washing esparto these engines are frequently made of large size, being built in plates as large as 24 feet long by 11 feet 6 inches wide by from 3 feet to 3 feet 4 inches deep, and capable of holding 30 cwt. of dry esparto. For rag breaking they are generally kept small and multiplied in number, better supervision and care in handling being obtained when the material is distributed in small quantities. They are successfully cast in one piece up to 16 feet long by 8 feet broad.

Fig. 15 is an exterior view of a recently constructed breaking engine.

Action of Washing and Breaking Engines.

The function of these machines is, first to wash away dirt and impurities which would be deleterious to the paper; secondly, to draw out the fibres, without unduly cutting them and to open them up to the action of the bleach; and lastly, to wash out the bleach liquor. When rags are to be treated, the engine is first filled up with water and the rags fed in. The roll is raised off the plate and acts as a paddle to circulate the contents, the spaces between the clumps of bars acting as the buckets of a lifting wheel. When the rags have circulated a few times, the roll is let down to merely brush the plate. The cock of the sand-trap is opened and the heavier dirt and impurities pass through the perforated plate, and are washed out through this cock, the lighter which are in suspension passing through the gauze into the buckets of the drum washer, which revolves at a depth of 13 or 14 inches below the surface. Clean water flows in continually at the water valve to make up for what passes out through the sand-trap and drum washer. When the water from the sand-trap begins to run clear, the cock is shut and the roll lowered down gradually on the plate, remaining thus until the rags have been drawn out into the state known as half-stuff, i.e. the fibre is out of rag, but not reduced fine enough to make paper. The drum washer is kept working until the discharge

from it runs clear, when it is raised and the bleach liquor run in.

The treatment of esparto is much simpler and demands less careful manipulation of the roll. In this case the washing is of much greater importance than the breaking, which is confined to merely opening up the fibres to the action of the bleach. But the washing has to be long and careful in order to carry away the silicious coating of the grass and the parts unfitted for paper making, which have been softened and loosened in the previous boiling and preliminary washing, but which have not altogether been disposed of. The roll is let down to brush the plate at starting and remains in that position throughout the operation.

The bleaching liquor is a solution of common bleaching powder (chloride of lime) in water. It is dissolved in a mixer, usually a circular or octagonal tank, provided with revolving agitators. In this tank it is kept stirred for at least two hours, and is then run down to a settling tank below, where it remains for seven or eight hours until the solution is perfectly clear. This settling tank is placed on a level to command the washing engines. When the drum washer has been raised and the clean water shut off, the bleach is run in and the roll is kept revolving until the desired whiteness is attained. Arrangements are made for admitting steam to the washing engine, as heat is sometimes necessary to assist the action of the bleach.

Bleach Chests.

When the bleaching has been accomplished, the bleach liquor is removed from the half-stuff, as the chlorine would have an injurious effect on the paper if allowed to remain. Several methods are in use. At one time it was customary in mills using rag, to run the half-stuff down from the breakers to a series of brick tanks built on the floor below. These tanks, called bleach chests, had false bottoms of perforated zinc plates, and the half-stuff was allowed to lie in them, in some cases for several days, until the liquor had drained through the perforations. The liquor was collected in a tank and pumped up to the bleach mixer, to be used in conjunction with new bleaching powder. By this means considerable saving in bleach was effected. This method was found to produce very good results with respect to colour, if not allowed to go on too long, but it was slow, and if prolonged too far it was found that the action of light had injurious effects both upon the colour and the strength of the fibre.

Hydraulic Press.

Another method is to run the contents of the breaker into a circular tank of the same capacity placed on the head of the ram of a hydraulic press. Such a press is shown in Figs. 16 and 17. The tank or press box *a* is lined with perforated zinc and two drain pipes *b*, are carried from the bottom down into two funnel pipes to carry off the bleach liquor. A false bottom *c*, made of a wrought-iron plate, perforated with holes and covered with perforated zinc, is suspended on a chain and balanced with a weight, so that it can be lowered to the bottom of the press box. The press box is guided vertically on four columns which support the head. The head *d* is a circular casting, whose diameter is slightly smaller than the press box, so that it may pass freely inside. The stroke is arranged so that the box can be lowered sufficiently far for the half-stuff to run easily to it from the breaker and so that the bottom of the box when at the top of its stroke shall be level with the beater house floor.

The press box is first lowered down to the bottom of its stroke, and the false bottom is let down into it. The half-stuff is then run in. The pumps are started, and the box is raised until it encircles the head, and the pressure gradually increases until from 30 to 40 cwt. per square inch is reached. The liquor is forced out through the perforations in the tank, down the funnel pipes, while the half-stuff is pressed into a block about 6 feet diameter by 1 foot thick. A catch engages with the chain of the false bottom when the ram is at the top of its stroke and suspends it in this position. The pressure is then taken off and the ram and press box lowered away from the false bottom, when the slab of half-stuff is left exposed at a convenient height for breaking up and distributing to the beaters.

Presse-Pâte Machine.

Another machine, used in dealing with half-stuff made from esparto, is the Presse-Pâte. Without going into a detailed description, it may suffice to say that it resembles the wet end of the Fourdrinier paper-making machine. Fig. 18 shows such a machine in front elevation. The half-stuff is run down into circular tanks, fitted with agitators on the floor below and shown dotted in Fig 2. From these it is pumped up to a series of settling or sand-tables, about 2 feet wide and made as long as convenient, sometimes as much as 300 feet. From the sand-tables it passes through the strainers or screens, which

keep back any knots, roots or other impurities. It then passes on to an endless wire gauze web through which the water and bleach liquor are drained, and having been subjected to the pressure of two pairs of rollers, is delivered to the trolleys for conveyance to the beating engines.

Direct System.

The remaining method to be dealt with is known as the Direct System. This method has at least the merit of simplicity. Each breaker is placed so as to command a beater, as shown in Fig. 1, and when washed and broken the half-stuff is run directly into the latter. It is obvious that if the engines are to be kept fully employed, the time taken for the two operations of breaking and beating must be approximately the same in the two engines. But many classes of stuff require very different periods of time, some needing longer in the one engine and some in the other. Where stuff requires long and careful bleaching, with less subsequent beating, a much larger quantity of bleach liquor has to be used to compensate for the shorter time permissible in the washing engine, if the direct system be adopted. Again, no matter how carefully the chlorine, liberated in the bleaching process, is removed by the drum washer, a certain amount will always remain in the pulp and requires to be neutralised in the beater. The use of a large quantity of bleach requires a correspondingly large quantity of neutralising agent, or antichlor, as it is termed. Hyposulphite of soda is one of the antichlors in most common use, and one of the results of its chemical action on the bleach liquor is the formation of hydrochloric acid. This passes down in the pulp to the paper-making machine, and, if present in excess, has an injurious effect on the machine wire. Of course, where quality and colour are not of importance, these objections do not apply, and in the production of the cheaper classes of papers the system has obvious advantages.

Beating Engines.

Whether the half-stuff is run direct or over the presse-pâte, for the final reduction to the fine pulp necessary to make paper, it has to pass through the beating engine. The ordinary beating engine is very similar to the washing or breaking engine, being constructed on the same principle. The roll carries more bars, being spaced three, sometimes four in a group, and runs at a higher speed, viz. from 1800 to 2000 feet per minute. Thus

to take an actual case, a roll of 51 inches in diameter, carrying a hundred bars, spaced four in a group, and working on a plate having 31 bars, runs at 135 revolutions per minute, or 1800 feet at the tips of the bars, and gives 418,500 cuts per minute. The bars of the roll and plate must be ground sharper for the beater than for the breaker. The pulp having been thoroughly cleaned in the washing engine, neither drum washers nor sand-traps are usually required. The time necessary for beating is from three to twelve hours, according to the nature of the paper, while the power required may be as much as from 40 to 45 horse-power per roll.

When the paper is to be made of very fine quality, these engines are lined throughout with sheet copper; the pipes to carry away the "stuff," as the pulp after beating is called, are also of copper, while the bars of the roller and plate are made of phosphor bronze. In some cases, the advisability of casting the roller block in brass and of copper-depositing the spindle has also been considered, in order that the pulp may never come in contact with iron; but as far as the author is aware, this has never yet been carried out in practice on account of the great expense.

Very many forms of beating engines have been patented, with the object of reducing the time and power required for the process, but the limits of this paper will not permit of the author entering into a description of any of the numerous varieties. The general opinion seems to be, that while many of the patent engines work very well on certain classes of stuff to which they are specially adapted, for general work nothing has yet been introduced so simple or so good as the old Hollander.

Refiners.

At one time it was customary in many mills making fine quality papers, to treat the pulp in three sets of engines. The washing and bleaching were done in the first set, breaking in the second, and beating in the third. This method produced very fine results, but was very expensive to work, and on that account is not so common as formerly. To a certain extent, however, the principle of intermediate beaters has been revived by the introduction of the refining engine. For a good many years these have been in common use in America, and in this country they are now being largely adopted. One of the best known among home mills, is Marshall's Patent Perfecting Engine, made by Messrs. Bentley and Jackson, of Bury. This engine is shown in Figs. 19 and 20. It consists of a hollow

cone, A′, carrying round the inside a number of steel knives, similar to those in the plate of an ordinary beating engine. A conical roller, A, also supplied with knives, works inside this. At the large end is a fixed disc, B′, and a revolving arc, B, each provided with a set of knives. The stuff from the beating engines is run down into a chest placed below them, whence it is pumped up into a service box, from which it flows to the perfecting engine. The stuff enters at the small end of the cone, and passes between the rapidly revolving roll and the shell. When it reaches the end of the shell, it passes between the stationary and the revolving disc, the knots being thus rubbed out.

When such an engine as this is used, the time in the ordinary beater can be much reduced, and the roll does not require to be kept so hard down, as the final disintegration is done in the perfecting engine. As the passage of the stuff through the refiner is continuous, one such machine is capable of dealing with the stuff from several beaters, so that the saving both in time and power is very considerable, while the system possesses the advantages of the old and expensive one of using intermediate beaters. When the stuff has passed through the beaters or the refiner, the preparatory processes are finished, and it is then run down to the stuff chests of the paper-making machine.

The preparatory machinery, hitherto described, has been for the treatment of such fibres as rags and esparto. Wood pulp, the staple fibre for the cheaper classes of papers, is almost invariably imported in this country, and its preparation is regarded as a separate industry. Its treatment in the paper mill is short and simple, it being generally broken up in an edge-runner grinding mill and then sent to the beaters and refiner.

The Fourdrinier Machine.

Stuff chests in this country are usually circular cast-iron tanks, or they are built in white glazed brick, and each has a revolving agitator, worked by a vertical shaft, and making about seven revolutions per minute. They are the storage tanks of the paper-making machine. A pair is supplied to each machine, coupled together with pipes and valves, so that the stuff pump may draw from either. It is necessary that there should be two chests, so that a beater can be let down into one, while the pump is drawing from the other, in order that the weight of paper on the machine may not be disturbed. The stuff pump is a single-acting plunger pump with ball valves,

which discharges into a small supply tank or regulating box, fitted with a valve for running the stuff to the mixing box and with overflow spouts to take the surplus stuff back to the chests.

On the Continent, stuff chests are frequently made of a U shape in section, and fitted with horizontal agitators. The stuff pump is dispensed with, and each agitator is provided at one end with a series of buckets which lift the stuff to the level of the mixing box. At the mixing box, a certain proportion of water is run in and mixed with the stuff from the chests, which would otherwise be too thick to make paper. The mixture then flows over a series of sand-tables, so that any dirt or grit may be arrested as far as possible, to the strainers. A great many different strainers are in use, each of which finds its advocate, but they may be divided into three classes, viz. suction, jog and revolving. Whatever be the type of strainer employed, the function of each is the same, namely, to keep back knots or strings in the pulp which may have been formed in the chests, or particles of raw material which may have escaped the action of the beating engine, and to permit only the fine pulp to pass to the machine.

The strainer proper consists of a number of brass plates, perforated by fine saw slits, varying in breadth according to the nature of the paper, from ·006 to ·025 of an inch. It is in the method of ensuring the passage of the pulp through the slit that the difference lies. In suction or bellows strainers the plates are flat, with a slight run towards the machine, and fixed in a vat. The bottom of the vat consists of a cast-iron plate attached by a rubber joint, and it receives a rapid vibratory movement, by means of cranks and connecting rods acting in conjunction with powerful spiral springs. The throw of the cranks may be varied from the smallest amount to a quarter of an inch, and the crank shaft makes usually about 600 revolutions per minute. The outlet spout is constructed so as to be always below the level of the stuff and to be air-sealed. The stuff flows over the upper surface of the plates, while the vibrating motion of the bottom of the vat creates a partial vacuum in the chamber below the plates, and so causes the fine stuff to pass through the slits into this chamber and thence to the machine.

In jog strainers the action resembles that of a riddle, the plates being fixed in a frame which receives a vertical motion from ratchet cams. The number of vibrations varies in different types from 1200 to 2200 per minute. In such strainers the pulp is shaken or knocked through the slits into the vat below, whence it passes to the machine, the passage of the stuff through the plates being also assisted by the slight suction action, due

to the motion of the plates in the liquid lying in the outer vat. In revolving strainers the plates are formed into a triangular or square box or into a circular drum, which revolves in a vat into which the stuff is introduced, combined with either a suction or jogging action.

One great difficulty experienced with strainers is in keeping them clean, and those of the jog type offer the great advantage of being easily managed in this respect, as the frame carrying the plates can be swung up and the plates washed through with a hose. In the ordinary rectangular jog strainer, however, there is some difficulty, both in getting rid of the dirty stuff, which does not pass the plates, and which requires to be sent to the auxiliary strainer, and in keeping the clean pulp which has passed from stagnating. A strainer which overcomes these difficulties very successfully has been recently patented by Messrs. Law and McNeil of the Balerno mills, near Edinburgh, and is shown in Fig. 21. In this strainer the outer vat is circular, in place of rectangular, and the plates are flat and arranged in an inner vat, also circular, which receives a vertical jogging motion, making 2200 vibrations per minute. At the centre of the disc of plates, there is a round opening from which a flexible rubber tube descends to an opening through the bottom of the outer vat. The inner vat is arranged so that it can be hinged up for cleaning, as shown in Fig. 21. In the outer vat, below the plates, are two horizontal revolving agitators, with spiral blades which keep the stuff in constant motion.

The stuff is introduced at one side of the inner vat, which, being circular, imparts to it a swirling motion. The heavy particles which do not pass through the slits naturally find their way to the place where there is least motion, viz. at the centre, and there pass through the opening down the central tube to the auxiliary strainer, while the clean stuff goes through the slits into the outer vat and so to the machine. An auxiliary strainer is commonly used in conjunction with the main strainers. This is generally of the jog type, and has plates of a slightly finer cut than those of the main strainers. The stuff rejected by these is run down to the auxiliary, and its object is to separate any clean fibre which may have remained in this stuff. The pulp which passes the auxiliary is withdrawn from its vat by a small pump and returned to the sand-tables.

Fourdrinier Machine. The Wire Frame.

The idea of making a continuous sheet of paper on an endless wire web was due to a Frenchman, M. Louis Robert, who

made the first trial of his machine at the mills of M. Didot at Essomnes in 1799. About two years later the invention was brought to England, and, thanks to the great energy and perseverance of the late Mr. Bryan Donkin and to the capital which Messrs. Henry and Sealy Fourdrinier laid out upon it, the machine was made a practical success. The patents were taken out in the names of the Messrs. Fourdrinier, and with their name the machine has always been associated. From the year 1803, when Mr. Donkin produced his first machine, it has undergone many improvements in many hands, until at the present day it has reached dimensions and is capable of running at speeds hitherto thought impracticable.

Fig. 22 shows one of the most modern machines which have been built in this country. It was constructed by James Milne and Son, Limited, of Edinburgh. The machine is not remarkable for great width, as it only carries a wire 110 inches wide, but it has been built to run at a very high speed for the production of news paper, and possesses all the latest improvements for ease in handling, speed-adjustments, and such like.

The stuff from the strainers flows into a wooden box of the same width as the machine wire and provided on the open side next the machine, with a sluice to regulate the flow of stuff, and known as the slice. The stuff passes on to the wire over the apron, which consists of a thin sheet of rubber, moleskin or American cloth, extending across the machine and reaching forward from the slice for a distance of about 12 inches. The pulp is prevented from flowing over the edges of the wire by a strap of rubber *a*, at each side, known as the deckle strap. The pulleys carrying these are so arranged that the distance between them can be altered to suit any width of paper desired to be run on the machine. The wire itself is an endless web of wire cloth having 60 meshes to the inch. The total length of that of the machine in Fig. 22 is 45 feet. The length varies very much with different classes of papers. Thus slow speed machines making writing papers run wires as short as from 33 to 35 feet. Common lengths for machines making the better class of printings and similar papers are 40 and 45 feet, while the length increases to as much as 55 feet on some fast-running news machines, and in America, wires of over 60 feet are met with. As the purpose of the wire is to secure the proper felting and interlacing of the fibres of the sheet and to drain away the water while still carrying the sheet forward, it follows that as the speed is increased, so must the length of the wire.

The wire is supported upon a series of rollers. The first or end roller *b*, round which the web turns, known as the breast roll, is of large diameter, from 9 to 10 inches in small and from

14 to 15 inches in wide machines. It is made of a seamless copper tube or of cast brass, pressed on a number of light cast-iron or steel rings keyed on a steel spindle. The other supporting rollers *c*, are called the tube rolls, and are made of solid drawn brass tube, with brass ends soldered in and steel gudgeons. These vary from 2½ inches to 5 inches diameter, according to the width of the machine. The side framing carrying the breast and tube rolls consists of two wrought-iron bars, supported at *d* on the fixed framing and at the breast roll end on rocking uprights. The intermediate supports *e*, are also made to take a rocking motion. The rolls carrying the returning side of the wire are supported on these intermediate rockers. The first pair of rockers *f*, are coupled together by a cross bar of cast iron, which is connected by a rod to a crank, with an adjustable throw, and keyed on the shaft of a cone so that its speed can be varied. The crank, with its gearing, called the shake motion, is driven at such a speed that the whole wire frame, from the rockers at *f* to the end pins at *d*, and with it, the breast, tube and carrying rolls, is vibrated to and fro, from 200 to 300 times per minute.

As already mentioned, the pulp flows on over the apron between the deckle straps, and wherever the wire is in contact with a tube roll, the water passes through. The purpose of the shake is to interlace the fibres, but as this interlacing can only be accomplished while the fibres are floating in water, great care and experience are required in the manipulation of the speed of the shake, so that too much water is not taken out at first. The water which passes through the wire is caught in trays *g*, placed inside the web, known as the save-all, and carried to a tank at the back of the machine. As this water contains a certain amount of fibre, it is pumped back again to the mixing box at the end of the sand-tables.

By the time the wire has reached the end of the side bars, at *d*, the tube rolls have almost ceased to be effective in draining off the water. It then passes over the suction or vacuum boxes *h*. These extend across the machine, inside the wire, and in this country are generally made of wood. They are from 9 to 12 inches broad, and are open to the top, with a central bar to support the wire. Each box is fitted with sliding or false ends and the width between these is regulated to suit the width of sheet being run, the space between the sliding and fixed end being filled with water to form an air seal. A pipe, with a regulating cock, connects each box to a set of vacuum pumps placed at the back of the machine. These pumps are so constructed that a steady and constant suction is maintained. The set in connection with the machine in Figs. 22 and 23 has four vertical

barrels, each 8 inches bore, having a stroke of 16 inches, double acting and running at 45 revolutions per minute. The number of suction boxes on the machine depends on circumstances. Two used to be considered sufficient for most machines, but three and four are now common. There is great diversity of opinion among mill managers on the materials to be used on the upper edges of the boxes, which are in contact with the wire. The wear on both box and wire due to the excessive friction in passing over the box is very great, and many materials have been tried with the object of lessening it. Beech, mahogany, lignum-vitæ, vulcanite, brass and glass have all been used, and each finds its advocate. Many attempts have also been made to produce a roller suction box, but hitherto with only indifferent success.

The effect of the suction box on the sheet of paper is very marked. Indeed it only becomes paper after passing the first edge of the first box, where a sharp line across the web denotes where wet pulp ends and paper begins. When it has passed the first box, it is in a condition to receive the water-mark, which is applied by means of a light roller, made of wire cloth with the devices worked upon it, suspended so as to lie in contact with the sheet as it passes on to the second suction box. This roll is called the dandy roll. Immediately after the last suction box is an automatic guide to ensure that the wire shall always run straight and true. This is accomplished by a device which moves the guide roller, where the wire passes tightly over it, through a small angle in such a direction as to counteract any tendency of the wire to move to one side or the other.

Still carried on the wire, the sheet passes through the couch rollers, at J, where it receives a considerable pressure. The name couch is a survival from the old hand-made mills, where the press on which the sheets were laid, between layers of felt, was known as the couch press, and these rollers fulfil the same purpose, as the paper is here subjected to its first pressure. The under roller is made of a brass shell, shrunk on cast-iron rings keyed on a spindle in the same manner as the breast roll. The upper one is either made in a similar way or is built up of mahogany staves. In either case, it is covered with a felt jacket. A pressure of about 1 ton is exerted by compound levers and weights at each end of the upper roll. This roll is also placed so that it does not lie vertically over the centre of the under one, but back at a small angle. The object of this arrangement is to enable the upper roll, by bearing upon the web, to press the remaining water out through the wire, before the full pressure of the rollers is applied. The under couch

roll drives the wire, which passes round it and back over the carrying rollers *k* to the breast roll.

This part of the machine, from breast to couch rolls, constitutes the wet end, and here the making is finished, the remaining part of the process being pressing and drying. Great improvements have been made in recent years in the construction of the wet end, with the object of facilitating the changing of the wire, at all times a somewhat laborious operation. As the web is endless, the breast and tube rolls, the suction boxes, save-all trays, and carrying rolls, which are inside the web, must be removed before a new one can be put on. These parts are therefore made as light as is consistent with strength and stiffness, and arranged so that they can be removed with least time and trouble. In the old machines, the save-all tray was made of wood in two large divisions, and this had to be lifted up over the side bars after the tube rolls had been taken out, and similarly replaced after the wire had been put on. In the machine shown in Fig. 22 these trays are light galvanised iron pans delivering into channels which carry the water to the back. Each part can be drawn out to the front of the machine underneath the side bar, by one man, without any lifting until it is clear of the machine. The cross channels can be similarly withdrawn. The suction boxes are also made to slide out on light removable rails. The lower couch roll, the heaviest part of the wire frame, is not removed, but the framing is cut out in a semicircle below it, so that by taking away the bearing, one end of the roll is exposed and the wire can be slipped over it. The upper roll is carried on a bell-crank lever, provided with lifting gear, so that it can be raised up clear during the operation.

Press Rolls.

Returning to the action of the machine, the making is finished at the couch rolls. The paper is then in a condition resembling wet blotting-paper, but is strong enough to support itself across the short span of from 6 to 8 inches which separates the under couch roll from the wet felt *l*. It is carried by this felt through the first press rolls *m*. These rollers are of large diameter; the under one in the machine shown in Fig. 22 being 18 inches diameter, and the top one 17 inches. The under one is of cast iron, with a jacket of vulcanised india-rubber, and works inside the felt, which, like the wire, is an endless web. The upper one, which runs in contact with the paper, is of chilled iron. Both are made on the antideflection principle—that is, the rolls are hollow and carried on heavy

steel spindles, which only bear in the central part of the roll, so that any bending strain is taken by the spindle and not on the body of the roll. It is absolutely essential, to make a proper sheet of paper, that these rollers (and the remark applies equally to the couch rolls and the calender rolls to be described later) shall bear upon each other equally throughout their whole length, and be perfectly straight and true. After turning they are therefore ground with emery wheels, in a grinding lathe, until they make a perfect joint, i.e. there must be no light visible at the line of contact of the two rolls when laid one upon the other and a lamp is passed along behind them.

The first press rolls squeeze out the greater part of the water still remaining in the paper and consolidate the sheet, while the upper side is smoothed out by the highly polished chilled roll. A second set of press rolls is provided through which the paper is passed in the reverse direction, in order to bring the under surface of the sheet, which was formerly in contact with the wire and wet felt, under the action of the chilled roll to equalise the surface. The paper in its passage through the couch rolls, being in a very soft and wet condition, receives an impression of the wire and of the wet felt in passing through the first press, and it is the purpose of the second press to remove this as far as possible. The paper has, however, become so much drier by the time it reaches the second press, that the action of this set of rollers never wholly removes it. To keep the upper roller clean and to free it from any paper which sticks to it, there is a phosphor-bronze doctor, or scraper, and in order that this may not mark the roll by always lying upon the same place, it is given a very slow traversing motion.

The brackets or housings of these rolls are on the American plan. The same difficulties met with in changing the wire have also to be overcome in changing the felts. The under press rolls work inside the endless web, and when a new felt is being put on, they have to be lifted up at one end and the felt slipped over them. It is obvious then that the more open the rolls are the better. In the old style of double-sided press roll brackets, as made in this country until comparatively recently, the upper roll was lifted by the screws, while the under one was raised up and the felt crushed through the widened out under-part of the bracket. A great improvement was effected by making one side of the bracket open, though the top roll was still suspended directly from the screws. In the American style, the under roll is carried in pedestals separate altogether from the housings of the upper roll. This bearing can be drawn off, leaving the end of the roll exposed to slip the felt over. The upper roll is carried on levers, which are raised by screws

and worm gear, actuated by hand-wheels accessible from the machine room floor, and the pressure is regulated by compound levers and weights, everything being within easy reach, and entirely doing away with the climbing on the machine frame necessary with the old style.

Drying Cylinders.

The paper having passed through the second press is then led over leading rollers to the drying cylinders. These are arranged in a double tier, so that the paper is in contact with a hot cylinder alternately on its upper and under surfaces. The cylinders are driven, one from the other, by spur wheels. The first one or two are usually worked without felts, to allow the free escape of steam from the paper, but to the others felts are applied, both to keep the paper flat and pressed out on the hot cylinders and also to prevent radiation and to assist in leading. In this country short felts are the rule, the cylinders being divided in groups of two or three and a felt worked on each group. As this felt absorbs a considerable amount of moisture from the paper, a drying cylinder of smaller diameter is provided for each, over which it passes on its return journey to the main cylinders. In America, on the other hand, it is customary to run the paper over one bare cylinder of smaller diameter, and then to felt all the others. One long felt serves the whole of the upper tier and one the under, and each is provided with one or two dryers. On the Continent again, even shorter felts than those met with in British practice are seen, machines running a separate felt to every main cylinder, with a felt dryer on each, being not uncommon.

The number and diameter of the drying cylinders has been increased greatly in recent years owing to the higher speeds required. From 40 and 42 inches diameter they have crept up to 54 and 60 inches, and while a machine built by Messrs. Milne in 1888, which frequently ran on news, had fourteen 48-inch cylinders; another, built in 1897, had twenty-two of 54 inches diameter, with eight felt dryers of 36 and 42 inches diameter. The exhaust steam from the driving engines is frequently used for heating cylinders, though many paper-makers use live steam at a reduced pressure. About 8 or 10 lb. per square inch is commonly employed, though if the drying surface be small in proportion to the speed, much higher pressures have to be used. The steam is brought to the cylinders by a pipe which runs alongside at the back of the machine having a branch and regulating cock for each cylinder.

The heat is regulated so as to gradually increase towards the dry end of the machine. The condense water is either taken out of the cylinders by syphon tubes or by lifting buckets, and trapped at the back of the machine.

The cylinders are turned and ground to a high polish, and are also bored through to ensure equal thickness of metal. They must also be carefully balanced. The ends are cast concave and lagged with blue steel sheet, the space between being filled with hair felt, to prevent radiation. The cylinder framing has undergone many changes in design. As the paper has to be led by hand from cylinder to cylinder until it is caught by the felt, it will readily be seen that, in order to secure safety at high speeds, the framing must be as open as possible. The old style of ring framing, very popular until a few years ago, because of the ease with which it could be erected and its lending itself to extension, has now largely given place to various forms of T framing. The ring framing is very unsuitable for high speeds as the supporting stools of the upper rings come across the line of the lead. In the T frame the line of the lead is quite clear, and this has been further improved by keeping the radius of the circled part about 3 inches less than that of the cylinder, so as to leave its edge exposed. This latest pattern is shown in Figs. 22 and 24.

Calenders, Damping Rolls and Winding Gear.

The paper is practically finished when it has passed over the drying cylinders, what remains to be done being a matter of surface or finish. The surfacing is done as far as the paper machine is concerned, by passing the paper through a series of chilled iron calender rollers. On such a machine as that shown in Fig. 22, which, as already stated, is specially adapted for making news, one stack of six rolls is sufficient. Two of the rolls are steam-heated. In some cases additional pressure to the weight of the rollers is applied by compound levers and weights, but where the surface required is not high and the rollers are properly ground, this is not necessary. The grinding of the rolls is the most vital point. A roll which is not truly parallel or which is marked in any way, will mark the paper at each revolution, and as this occurs at the completion of the process it is a very serious matter. Very great care is, therefore, expended upon them in order to bring them to a perfect joint. Each roll is ground by itself and laid upon its neighbour in the stack and tried in all positions by the light test.

In a stack of five or six rolls a certain amount of deflection

will be set up in the bottom roller by the weight of those above it. In order to resist this the bottom roll is made of very large diameter, with very heavy journals, but in addition it is also slightly barrelled on the body, so that its upper surface is brought parallel to the other rollers by their weight acting upon it. When pressure is applied to the top roller by levers, this roller is also barrelled. The reduction in diameter at the ends is very minute, the taper being usually carried along the body for about 4 to 5 inches from each end, but the precise amount to be allowed would be difficult to state, and can only be judged by experience and attained by very careful manipulation of the grinding machine. Higher class papers will require more than one stack of calenders, and it is usual on machines for making such to separate the cylinders into two groups, having two or three in the second. Between the two groups a pair of chilled rolls is introduced, known to engineers as smoothing rolls and to paper-makers as intermediates. The object in placing these rollers in this position is to press the paper between the hot rollers before all the moisture is taken out of it. The number of rollers required after the second group of cylinders will depend on the surface required, one stack of three and two of five rolls being a common arrangement.

As a high glaze does not seem to be attainable without a certain amount of surface dampness, various arrangements have been introduced before passing it through the calenders. One method, not so common as formerly, is by passing it over a pair of copper or brass rollers through which cold water is kept circulating. A fine spray of steam is blown against the rollers, just before the point of contact with the paper. This is condensed by the cold water into a thin film of water on their surface, which is communicated to the paper and carried by it to the calenders. An older method which has lately been reintroduced is known as water doctoring. In this system a thin film of water is introduced at each nip on the first or three-roll calender, the glaze obtained by this method being very high. All that now remains to be done is to wind the paper into reels. When large webs are being made, this is conveniently accomplished by winding the reel by friction with a drum, but smaller webs are wound on a reel driven by a friction pulley, which slips between its plates as the diameter of the reel increases.

Driving Gear.

The driving gear of the paper machine is one of the most important points, and calls for the greatest care in design.

Until comparatively recently it was customary to place the engine opposite the first press rolls and to drive from it at a reduced speed through a pair of spur change-wheels to the first press roll shaft. On this shaft, pulleys were keyed and belts led to the couch roll shaft, second press and cylinder shafts. From the cylinder shafts, belts were again taken to the second cylinder and smoother shafts, and again from the second cylinder shaft to the dampers, calenders and reeling apparatus. This method had many disadvantages. The speed of the belts was never very high, and to get belt power, and to ensure steadiness in driving, the pulleys had to be made very wide and of large diameter. It only permitted of the very crudest methods of adjusting the speeds of the various parts of the machine. The paper in its passage along the machine must be kept at a certain tension between the various rollers. The first press rolls must go a little quicker than the wire, the second press quicker than the first, and so on, gradually quickening as the paper dries. Experience can, in a general way, allow for the amount of tightening required, and the sizes of the pulleys can be calculated accordingly in the first instance, but it cannot allow by calculation for the slight differences in speed which will be required when the paper to be run is changed from thick to thin, or when a new jacket is put on the couch roll, or the wet felts changed, or any of the many small things which frequently occur to alter the tensions or draws, as they are called, and which necessitate a slight alteration in speed of one part of the machine or another.

The method adopted for changing the speed with this style of gearing is the unsatisfactory and dangerous one known as bulking the pulleys, and is done by smearing pieces of felt or belting with resin and slipping them in between the belt and the pulley, at the ingoing side of the belt, so that they adhere to the face of the pulley and increase its diameter, the driver or driven pulley being bulked according as the part affected is required to go faster or slower. When the space was at all confined at the back of the machine, moving about it when running involved some danger, and in some cases was quite impossible. Notwithstanding its obvious disadvantages this style of gearing continued to hold its own in this country, and although the cone-driving method about to be described was in use in France as far back as 1877 and had found its way to America and displaced expanding pulleys (themselves a great improvement on the bulking method) shortly afterwards, it is only within the last seven or eight years that it has been seriously taken up in Britain, and by far the greater number of machines are still running on the old style.

The cone system, shown in Fig. 28, is said to have been first adopted by Messrs. Jouffray, Cadet and Sons in France, and afterwards to have been introduced into America by Mr. Marshall; it is now widely known as the "Marshall Train." In this train a shaft is coupled by a claw coupling *a* to the driving roller of each set, and on this shaft, a bevel-wheel *b*, usually of the mortise type, is keyed. A short countershaft *c*, carrying a bevel pinion *d*, and a cone pulley *e*, provided with a friction clutch, is placed at right angles. A long shaft *f*, carrying similar cones to those on the countershafts, runs overhead. The cones are generally from 30 to 36 inches diameter and have a face width of from 3 to 4 times the breadth of the belt. They are tapered about $1\frac{1}{2}$ inch per foot width. A belt shifter, worked by a screw, is provided, and a very slight movement of the belt to one side or the other is sufficient to alter the speed as may be required. This arrangement permits of free access to all parts of the machine when running, occupies very little floor space and provides an easy, safe and fine speed adjustment.

The objections to it are, the use of bevel-wheels, which, especially when made mortise, are very expensive, have a low efficiency and an objectionable end thrust; the attendant has to go to the back of the machine to adjust the speeds, and the belts, running, as they are, nearly vertical or at a very high angle, have not the same grip on the pulleys, as when running horizontally. To overcome these disadvantages, Mr. Thomas T. M. Lumsden introduced, in 1897, a new system of cone gearing which has given most satisfactory results, and is known as the Lumsden patent quick-speed driving train. In this system the belts run parallel to the machine and are placed horizontally, the bevel wheels are dispensed with and replaced by engine-cut or helical spur-wheels, and the screw belt shifters are coupled to light shafts which are brought across the machine to the front side, so that all the adjustments are at the attendant's hand and he never requires to leave the front of the machine. The arrangement is clearly shown in Figs. 23, 26 and 27. This system retains all the advantages of the Marshall train and does away with its objectionable features.

The old system of varying the speed of paper on the machine by means of change-wheels, has now largely given place to an arrangement of speed cones in connection with the engine governor. While the old method involved the stoppage of the machine even for a very small alteration in the speeds of paper and the labour of taking off and replacing heavy spur wheels, by the new system the speed may easily be varied a hundred feet per minute without stopping the engine. The

pumps, strainers, shake motion, etc., should always go at a constant speed, and are now, on all modern machines, driven by a separate engine.

Speeds of Paper-Machines.

Carl Hoffmann, in his well known treatise on the manufacture of paper, published first in 1873, speaks of well constructed machines being capable of making news paper at speeds of from 110 to 130 feet per minute. Mr. J. W. Wyatt, in an admirable paper on paper-making, contributed to the Institution of Civil Engineers, in 1884, says:—

"The average speed of a paper-machine on fine writings of medium weight is from 60 to 70 feet per minute, but on thinner weight, the machine can be driven up to 120 feet per minute." Probably since then, the speed of machines making writings has not advanced much, but certainly it has gone up on news machines.

The author well remembers, a dozen years ago, hearing of machines running on news at 250 feet, which was then considered very fast indeed. The author is acquainted with a machine which was started in 1898, and has since then run continuously at 360 feet per minute, and although only carrying a wire 106 inches wide has produced 107 tons of paper per week. Upon some recent occasions it has attained a higher speed than this. This, so far as he is aware, is the highest speed yet attained on a British machine.

From America come reports of 500 and 550 feet per minute, and recently one of the machines at Messrs. Lloyds' mills, at Sittingbourne, built by the Pusey and Jones Company, of Wilmington, Delaware, is reported to have made paper at 500 feet per minute from Scandinavian wood pulp. It would be interesting to hear the opinions of paper-makers on the relative merits of British and American paper-making machines, and why it is that such high speeds are not heard of oftener in this country, though probably there is a great deal of truth in the frequently expressed opinion that the nature of the wood pulp obtained in Britain does not permit of such fast running. The author is convinced that British engineers are both capable and willing to produce machines to run at any speed the paper-maker may demand.

Conclusion.

There are several other forms of paper-making machine besides the Fourdrinier, and many machines used in the finishing of paper which must be left unnoticed from want of space.

The subject of this paper is a very extensive one, and the author feels that he must crave the indulgence of the Society for having given little more than an outline of it. He also desires to thank all those who have so kindly assisted him with drawings for the illustrations of the paper.

DISCUSSION.

The President said that there was apparently only one form of machine for making paper described in the paper. As there were several points on which the practice might differ in other parts of the world, it would be desirable to have some particulars of other machines if there was anyone present who had a knowledge of them. The plan of the machines in Figs. 1 and 2 allowed, apparently, a very simple sequence in the making of paper, and gave a perfect run from the raw material down to the finished article as it ought to leave the mill. As the author had pointed out, the arrangement could be duplicated without interfering with the working portion of the mill already laid down. The author mentioned a pressure of from 30 to 40 cwt. per square inch on the hydraulic press. He should like to know whether that pressure was on the head of the ram, or on that portion of the ram which pressed against the material itself. The author had remarked on the accuracy which was necessary in the manufacture of the rolls. When the size of some of the rolls was taken into account, the exactness with which the rolls touched upon one another was very remarkable. There were five or six of them one above the other, and each one required to touch the next to it throughout its whole length without the slightest space between the two. The question of speed was, he believed, one of the most important points to be thought of in the future. Machines of higher speed would now require to be made to take the place of the present ones, which were becoming obsolete. The President concluded by proposing a hearty vote of thanks to Mr. Henderson for his excellent paper.

The vote of thanks was accorded with acclamation.

Mr. W. H. Salmon said that he had been informed that the esparto vomiting boiler only worked when the lid at the top was open, but that when the boiler was closed a uniform pressure was produced within, and that therefore the vomiting ceased. He should, however, like to know whether the truth of that statement had ever been verified.

There was one small detail in connection with the paper-making machine that had been omitted—viz. the felt-washer. Mr. Henderson had explained the improvements made in press roll brackets to facilitate changing the felts, but the method now in use for washing the felts continuously saved them from being taken off until they were worn out. The speed of paper-making machines was a very important point, and it was being gradually worked up day by day, but being one of the old school of engineers he (Mr. Salmon) did not believe all he heard about that matter. The Marshall train and other similar methods of driving mentioned by Mr. Henderson were splendid arrangements. They were not, however, easily applied to old machines without considerable cost. He (Mr. Salmon) thought, however, that before many years the Marshall train would be generally adopted for medium class papers.

Mr. James Beveridge said that he looked upon Mr. Henderson's paper as one of the best descriptions of paper-making machinery he had met with. At the same time one recognised that Mr. Henderson had run over the gamut of paper mill machinery and appliances in the good old orthodox style, and he did not give much opportunity for an engineer who had dipped beneath the surface of the subject to find many faults. The author had sounded a note of warning in the body of the paper not to touch on the more modern forms of beating engines. He supposed that was because they had been patented, but why the patent laws should debar one from discussing a machine which had been patented passed his comprehension. However, he agreed with Mr. Henderson in the statement that the old Hollander worked thoroughly well, and it would, he believed, compare favourably in point of economy, in working efficiency and in general adaptability with the new forms of beating engines.

When Mr. Henderson was describing the details of the newer paper machines, the description called to his (Mr. Beveridge's) mind some of the American machines which he had seen when in the United States. It had always been a matter of disappointment to him that English engineers did not design from an artistic point of view as the American engineers did. The first thing that impressed him on going into an American machine house was the artistic appearance of the paper machine. There were one or two American machines running in this country, and there was no doubt that they were very striking and very impressive, much more so than English machines. If the American machines were examined very closely, it would be found that strength was given where it was required, and that

where it was not required it was not given. He believed that the Americans had generally reduced the various parts to a matter of measurement and calculation, and did not construct their machines on any rule-of-thumb method. With regard to speeds, he had seen machines running in America at over 450 feet a minute, though he had not seen one running at 500 feet. The one running at 450 feet made upwards of a ton of paper an hour. He believed that at Sittingbourne in Kent there was a machine capable of making fully a ton of paper per hour. A great deal of credit was due to Mr. Henderson for bringing the details of the subject so thoroughly before the Society.

The PRESIDENT, alluding to a remark of the last speaker, said that he thought he should be right in mentioning the fact that by an unwritten law there were two subjects which were not discussed at the meetings of the Society. One was politics, and the other was patents.

Mr. J. GRANT said that he was exceedingly pleased that he had had the opportunity of hearing the paper. He could not speak from an engineering point of view, but he could, perhaps, speak from the point of view of a paper-maker. He had listened with a great deal of interest to the paper. The manner in which Mr. Henderson had handled his subject was certainly very good, considering the large amount of space that he had to cover. Of course it would be quite impossible in a paper of that description to touch on every point, and they could all recognise the difficulty of including every point in the process so as to suit everybody's views. For instance, something might have been said with regard to the treatment of sewage, which was a very important point in a paper mill. It was mentioned in the early part of the paper that from 100,000 to 180,000 gallons of water were required per ton of paper. A maker was very lucky if he could get such a quantity of water as that. He knew mills which made paper with a quarter of that quantity of water.

As to speed, he knew that machines ran at fast speeds nowadays. He quite agreed with the engineer's view that the question of speed was largely one for the paper-maker. If the manufacturer wanted a particular speed, the engineer could supply him with a machine for it. To get up speed was to some extent a question of quality. If they wanted to have a speed of say 400 feet they must put backbone into the material.

Mr. NEIL TURNER said that he thought the paper had been somewhat on old lines, and was not altogether up to date; but

he recognised the fact that it was one prepared for a society of engineers, and not for paper-makers only. He thought that Mr. Beveridge struck the right note in pointing out that English makers had not been quite up to date in manufacturing machines. There were several American machines now running in this country, and the opinion was held by some that the material and general workmanship of American machines were not so good as those of English make, and that the bill for repairs might in a few years' time, be somewhat greater than the cost of repair of English machines. At the same time, it must be admitted that the American machines were adapted for their work. They were built for fast running, they were not so heavy as English machines, and there was no doubt that there were a great many little points about them for which the Americans deserved very great credit. The author of the paper, for instance, talked of the difficulty of changing wires and felts. The Americans had introduced contrivances for making that a very simple matter, so that the wires might be changed in about two hours instead of five or six. That was, of course, a very important consideration.

The author had mentioned refining engines. They were very good things, but he had omitted to state how much power they used. He should like a little light on that matter when the author replied. Another point was the saving of fibres. Everything must be done now to economise. In modern mills there would be found very elaborate means for catching the fibres. He thought, probably, the best system was that which consisted of settling tanks where the water was allowed to remain until the fibres settled at the bottom. The water was then run off and used over again, and the fibre taken out and pressed into cakes, and in that form put into the beaters. As to the speed of machines, he could only state that there were two paper-making machines at the present moment at Sittingbourne running at 400 feet a minute. Those machines were designed to run at 500 feet, and he had no doubt that in a very few weeks or months they would be running at that speed. The difficulty of speed was not with the machines, but with the men. The machine tenders wanted a certain amount of training in order to tackle machines running so fast, and they could only become used to them gradually. He believed, however, that high speed was being worked up to in quite a satisfactory way.

Mr. F. W. R. Dewdney, referring to the statement made by Mr. Grant to the effect that when running at a very high speed it was necessary to use a much better quality of raw material,

said that he could not see how such was the case. He believed that high speeds had been introduced from America, and so far as he knew, no other country had produced paper so cheaply. The American news which had been sold in this country at $1\frac{1}{4}d.$ less $22\frac{1}{2}$ per cent. was certainly made from the commonest materials, and, it was stated, on high-speed machines. He therefore thought that high speeds must be more dependent on the building of the machine than on the quality of the raw material. One of the largest mills in Sweden was now being built where the machines were to run at very high speeds, and the raw material would almost solely consist of mechanical wood pulp.

Mr. W. Harris said that although, as had been said, the paper brought out some old things, he had been deeply interested in it. As regarded the damping arrangements mentioned, he thought most mills at present did that with a spray damper. With respect to the speed of machines and the running of paper over the machine, the author's statement was very misleading, as instead of going faster from the press rolls right through the machine, it had to be slacked back, for, as was well known, the paper as it dried contracted both in length and in width.

Mr. J. Bernays asked the author, with regard to the clearing of the paper of the bleach, whether, instead of a hydraulic press, a centrifugal machine had ever been used for the purpose of consolidating the half-stuff, and getting the water and the bleach out of it.

Mr. Henderson, in replying upon the discussion, thanked the meeting for the very cordial vote of thanks which they had given to him, and the way in which they had received his paper. One or two of the speakers had said, and had rightly said, that he had gone over old lines. In doing so, he remembered that he was addressing a society of engineers, many of whom were unacquainted with the subject, and his purpose had been to give a general idea of the processes involved in the manufacture of paper. He was quite aware that many of the processes to which he had referred were now somewhat out of date.

As to the President's question about the pressure on the half-stuff, he should have stated that the pressure was 30 or 40 cwt. on the ram, but that pressure, when distributed over an area corresponding to a diameter of 6 feet, was very much reduced by the time it got to the half-stuff. He believed that the pressure worked down to about 60 lb. on the square inch.

He was very much obliged to Mr. Salmon for referring to

the felt-washer, for it had entirely escaped his memory, possibly, he supposed, because the machine that he was describing had not yet been fitted with the felt-washer. But in modern machines the felt-washer was undoubtedly an improvement, and increased the life of the felt to a very large extent. He thought that what he had said applied to the remarks of Mr. Beveridge and Mr. Neil Turner. With regard to the question as to the use of centrifugal machines, he was not aware that such a machine had ever yet been tried on the half-stuff. He thought, however, that a rather more drastic process was needed than the centrifugal machine could supply.

The following communication was sent by Mr. Joseph Dixon, who was unable to attend the meeting :—

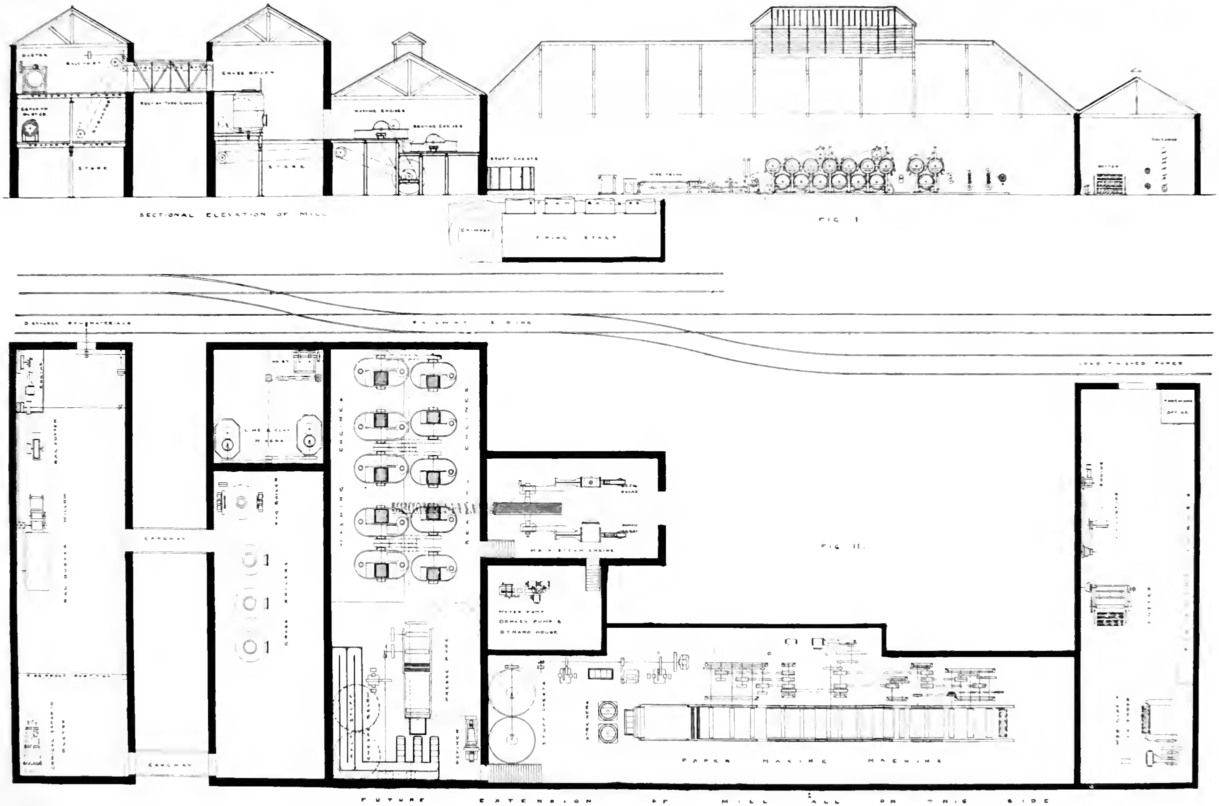
I have had considerable pleasure in reading Mr. Henderson's paper on the manufacture of paper-making machinery. As a paper-maker, I would observe that the enormous developments which are now in progress in the United States and Canada (where in one works alone it is intended to produce some 250 tons daily of news paper, mostly for the European market) indicate the stress of foreign competition that British makers must be prepared to encounter. It can only be by the engineers and paper-makers of this country working together in the closest alliance that home producers will be able to hold the field. Of course paper being a fragile commodity, and liable to serious damage in transit, and the British maker being on the spot, gives us a considerable advantage. But that the stress is at our doors is proved by the remarkable imports into this country during recent years, and by the fact that whereas there have only been about three or four new paper machines laid down in this country during the past five years for the manufacture of news, in the United States there have been 30 or 40, and the imports into this country are somewhere about the production of these 30 or 40.

It is probable that the paper machines recently laid down in this country are quite as good as, if not superior to, those made in America. Certainly they are more solid and substantial, and whatever excess of production the latter are capable of is owing to the live fibre they are fed with, the wood retaining a curl and crispness which our imported wood loses in transit.

Again, it is doubtful whether the water powers of America are really much cheaper (taken in connection with the cost of installation and cost of transit of the product to this country)

than ours at home, especially when the plant is favourably fixed near a coalfield.

I think the future improvements in apparatus will take the direction of developments of the wet end of the paper machine, and that a more effective interlacing of the fibres whilst in the fluid condition will be effected; and I am hopeful that some new ideas and devices for this end may be shortly forthcoming.


SECTIONAL ELEVATION OF MILL
FIG. I
FIG. II
PAPER MAKING MACHINE
FUTURE EXTENSION OF MILL ALL ON THIS SIDE

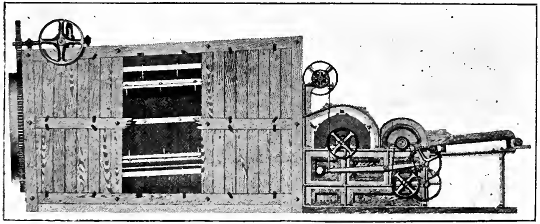


Fig. 3.

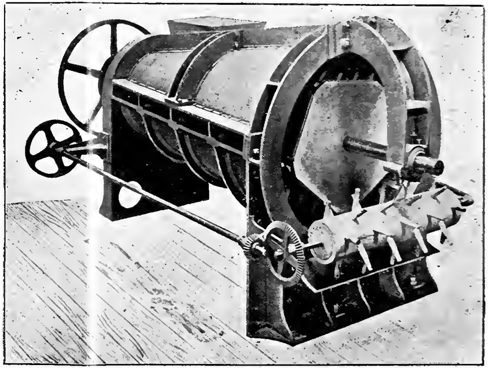


Fig. 4.

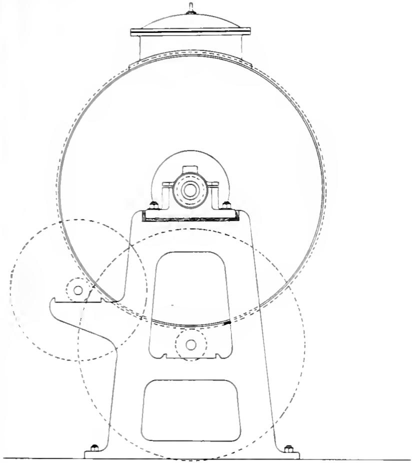


Fig. 6.

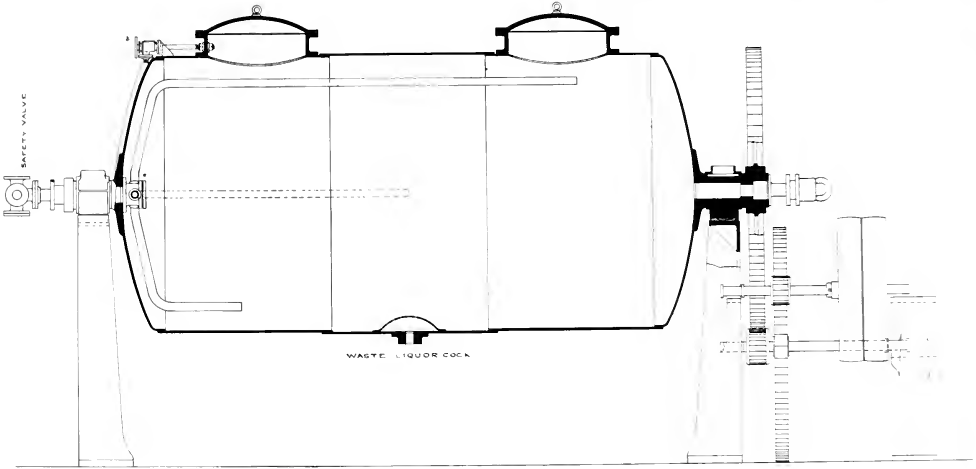


Fig. 5.

ELEVATIONS OF FIBRE BOILER

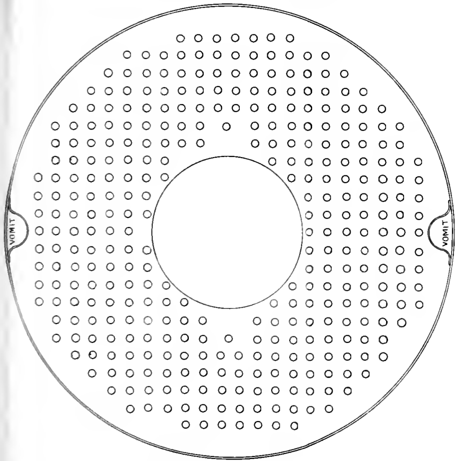


FIG. 8.

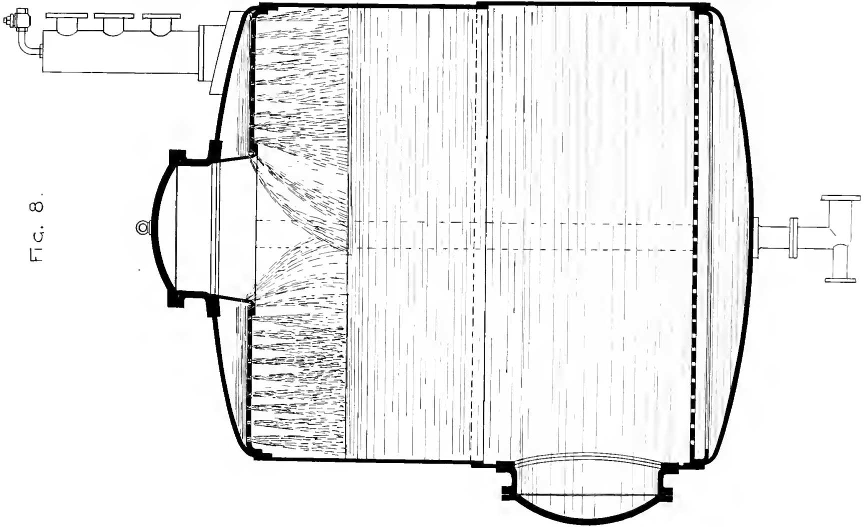
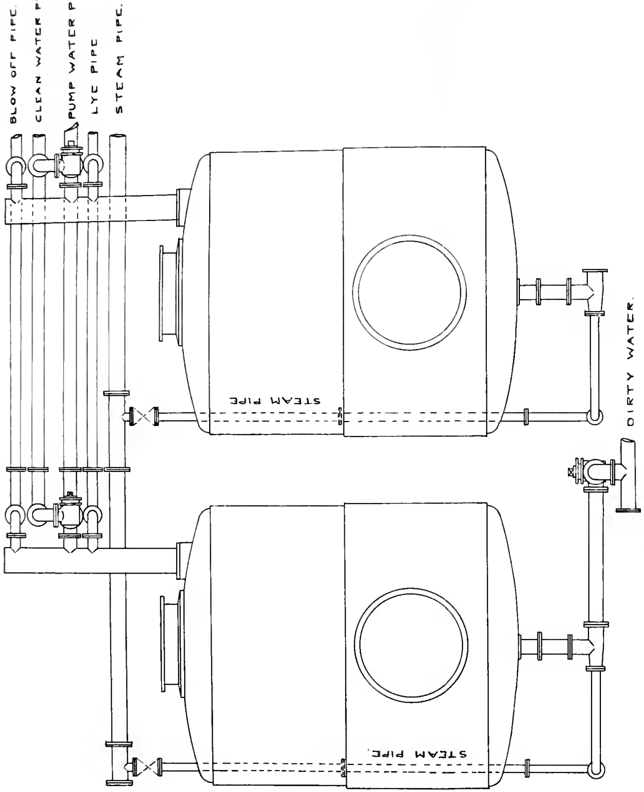


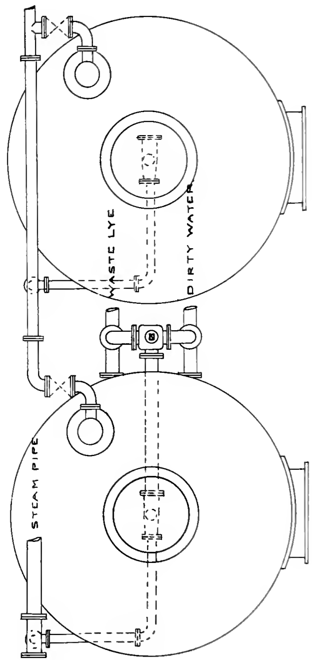
FIG. 7.

PLAN & ELEVATION OF GRASS BOILER



ELEVATION

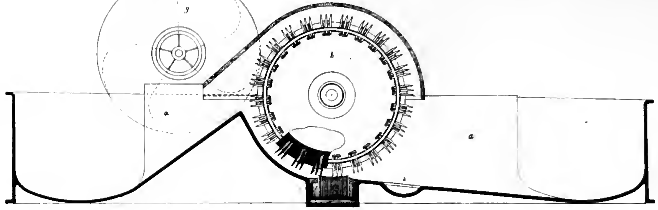
Fig 9.



PLAN

Fig 10.

Plan & Elevations of Beating & Washing Engine



Longitudinal Section

Fig. 11.

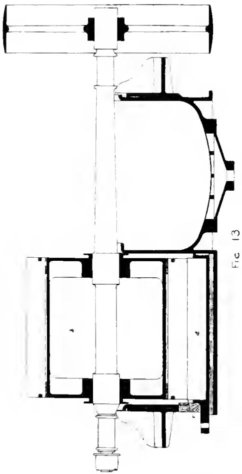


Fig 13

Cross Section

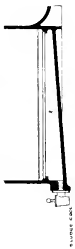


Fig 14

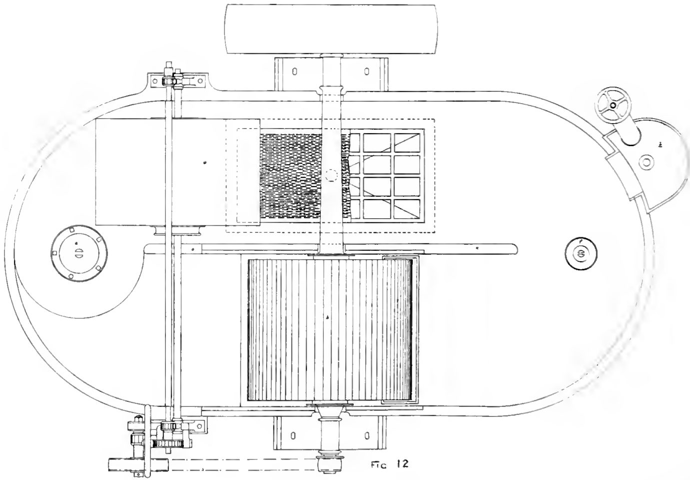


Fig 12

Plan

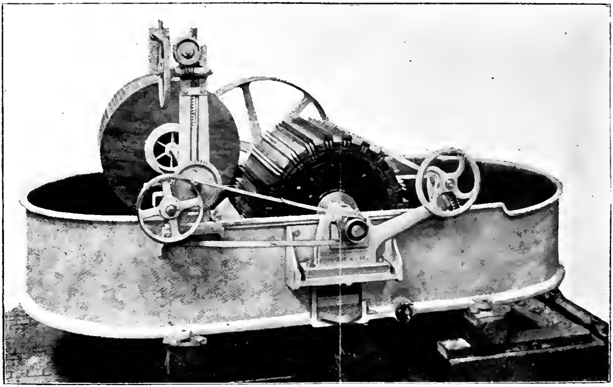


Fig. 15.

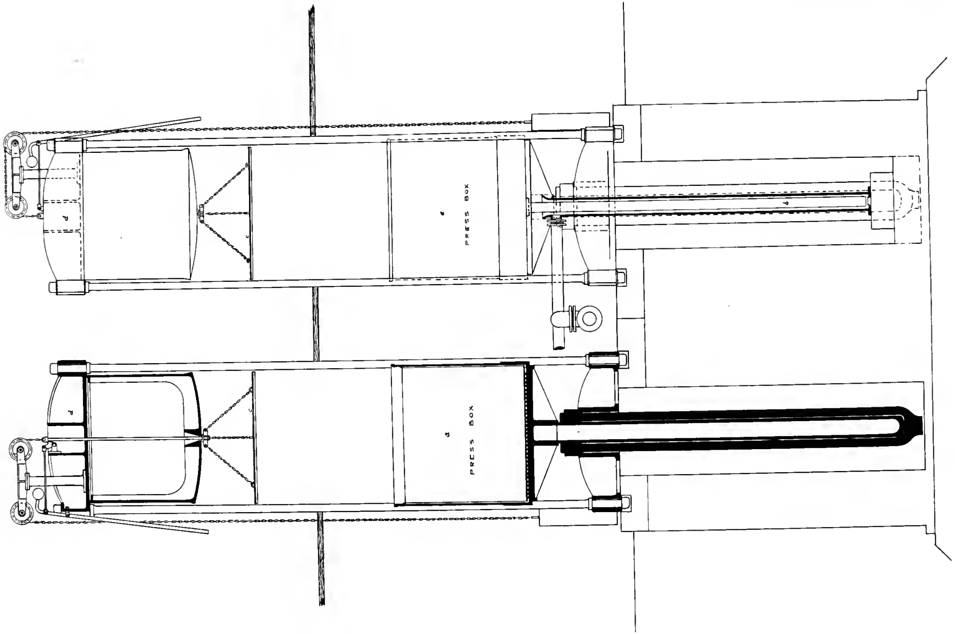


Fig 16.

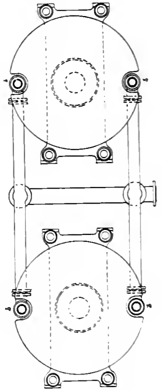


Fig 17

PLAN & ELEVATION OF HYDRAULIC HALF STUFF PRESSES

INCHES FEET

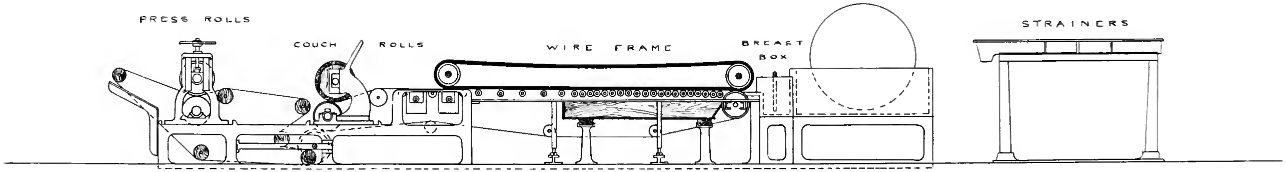


FIG. 18.

ELEVATION OF PRESSE PÂTE

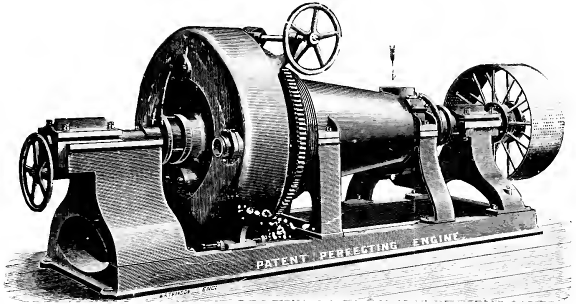


FIG. 19.

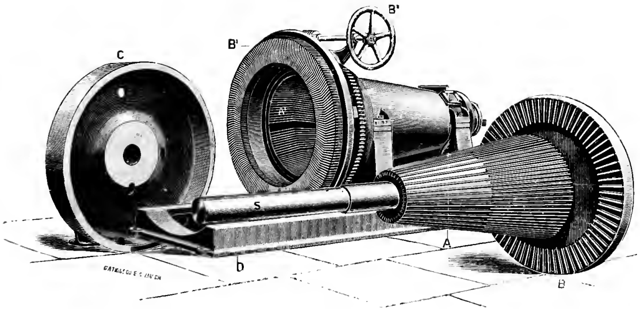


FIG. 20

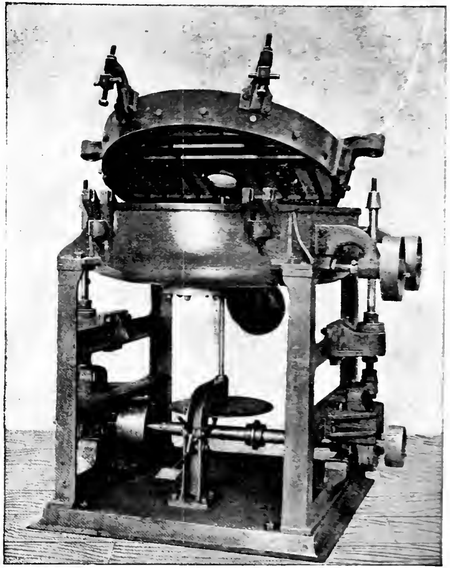


FIG. 21.

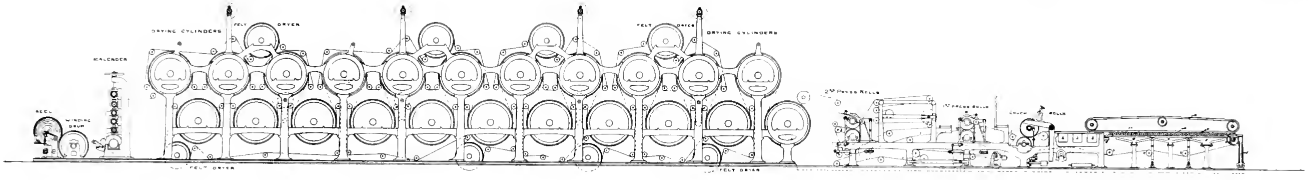

DRYING CYLINDERS
FELT DRYER
FELT DRYER
DRYING CYLINDERS
KALENDER
REEL
WINDING DRUM
2nd PRESS ROLLS
1st PRESS ROLLS
COUCH ROLLS
FELT DRYER
FELT DRYER

Fig. 22

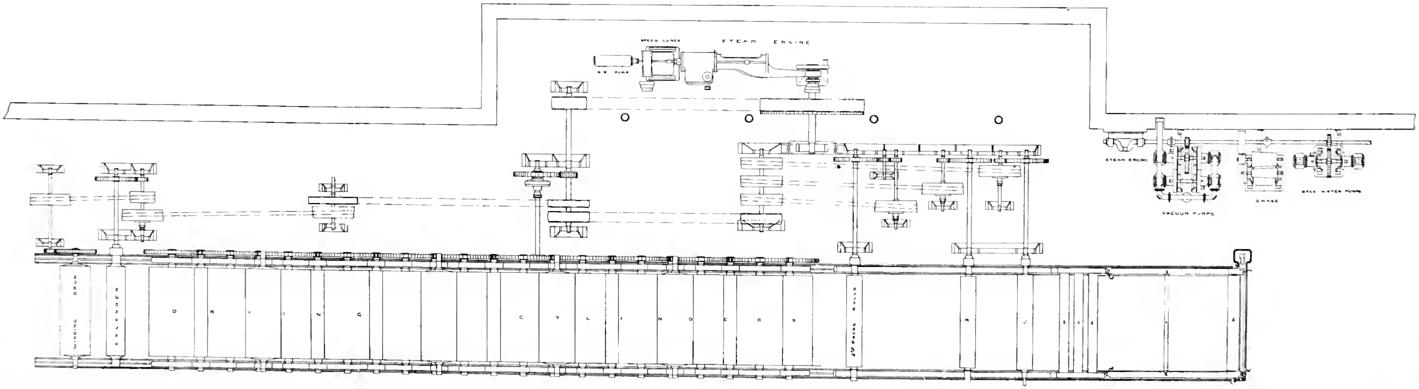

SPEED CONES
STEAM ENGINE
STEAM ENGINE
VACUUM PUMPS
SHAKE
BACK WATER PUMPS
D R Y I N G C Y L I N D E R S
2nd PRESS ROLLS

Fig. 23

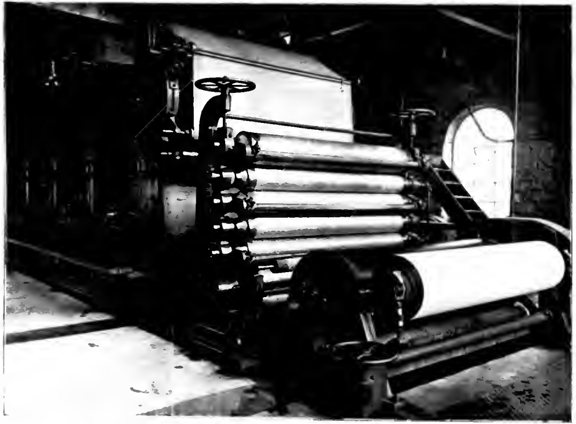


Fig. 24

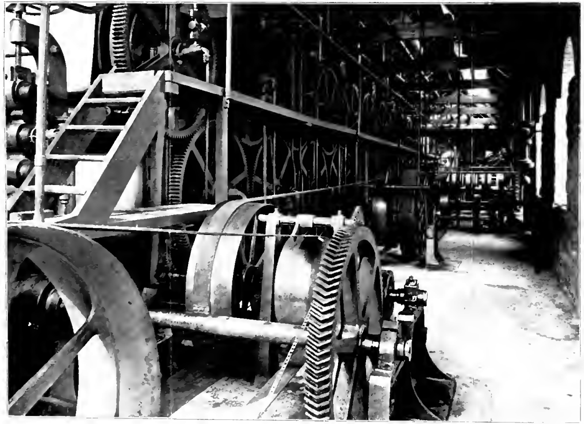


Fig. 26

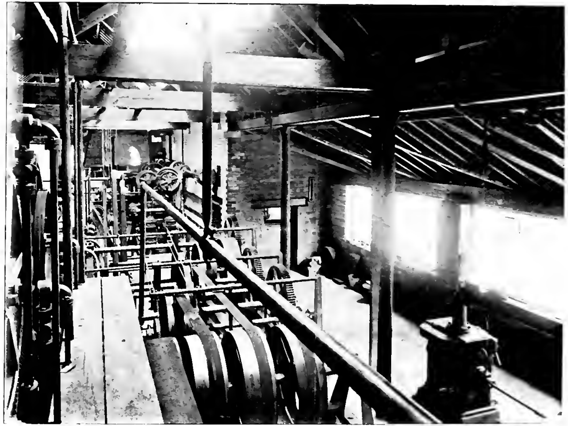


Fig. 27

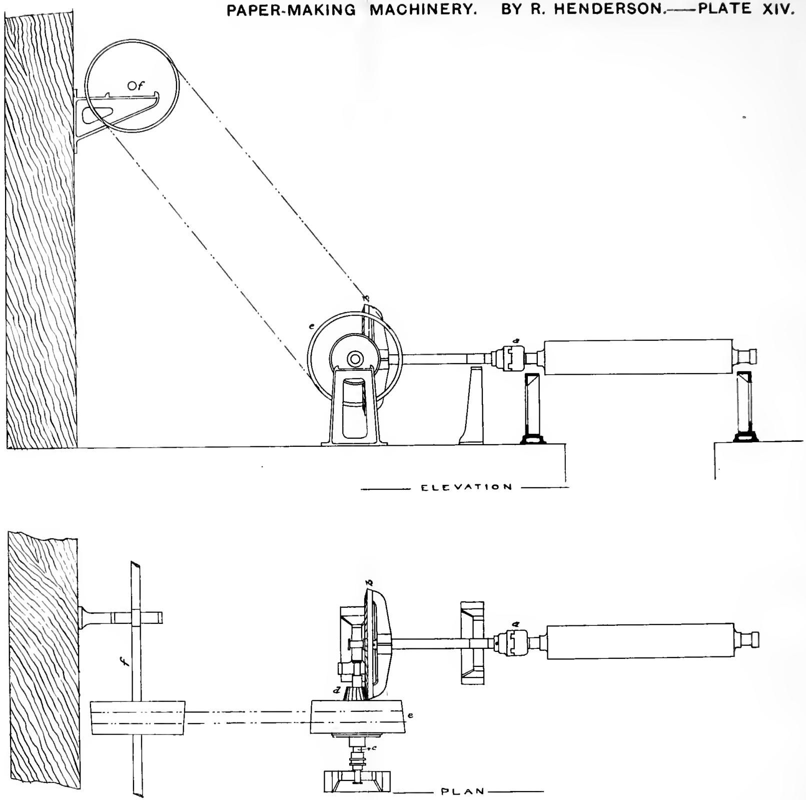


FIG. 28.

November 5th, 1900.

JAMES PATTEN BARBER, VICE-PRESIDENT, IN THE CHAIR.

NOTES ON ENGLISH AND FRENCH COMPOUND LOCOMOTIVES.*

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MR. FRANCIS WILLIAM WEBB, Mechanical Engineer-in-chief of the London and North Western Railway, may fairly claim to be the introducer of the compound system into the practical politics of locomotive designing and construction. That locomotive compounding had previously been the subject of various desultory and sporadic experiments by Monsieur Mallet and other engineers, does not affect this fact. When Mr. Webb placed his engine, "Experiment," No. 66, on the London and North Western metals in the year 1882, he virtually inaugurated a new era in locomotive engineering.

To the question of compounding for locomotives the author has devoted close attention ever since its advent in 1882, and it is probable that he has made as large a number of experimental observations as any other engineering writer, if not a larger. At all events, he has been unable to discover any other series of complete observations and notes which bear any comparison with his own in point of fulness and extent, although he has sought assiduously to find some, with the view of ascertaining how far his own experiences are borne out by those of other competent observers or agree with theirs. Consequently, he is compelled to base entirely upon his own personal experiences such conclusions as he has felt warranted in arriving at.

It may clear the ground at the outset to state, first, that the author approached the question absolutely without prejudice, either in favour of compounding or against it. That he entertained doubts as to the feasibleness of employing effectively in locomotives a principle which had proved successful under the widely divergent conditions of marine engineering may be at once admitted ; but that was all. Secondly, the subject will be reviewed purely from the practical and scientific viewpoint of its value in ordinary regular service as ascertained by direct

* A Society's Premium was awarded to the Author for this paper.

observation, and not from the merely academic side of its theoretical or diagrammatic merit or demerit. Engines of the various compound types will be reviewed and judged, not on the score of the diagrams they may have given, or the theoretical horse-power they have nominally developed, but on the basis of the loads they have pulled, the speed they have attained or maintained with loads on different gradients, and the ease or difficulty with which they start in various circumstances. The question of theoretical horse-power developed is a very interesting and even useful one from an academic viewpoint. But theoretical horse-power is not always correlative with practical efficiency. Not long ago, some very ably conducted experiments with British express locomotives produced the somewhat depressing result of demonstrating that certain engines which developed the largest horse-power did the smallest practical work. Such an outcome was distinctly discouraging. So that method of procedure will be avoided on the present occasion.

The object of compounding may be stated in a single word as economy. This, however, does not mean mere diminution of actual working expenses by reduction of fuel-consumption, or otherwise. The economy sought is rather that of force, and of the means by which force is produced. Compounding is used in cases where coal-consumption is a matter of quite secondary consideration, or where the non-compound plan would assuredly be employed were it the more efficient of the two, the supreme desideratum being power. In reviewing the whole question it is necessary that the mind should be kept clear of inaccurate or irrelevant points, for there is no doubt that much unwarrantable prejudice against the principle of locomotive-compounding has been excited through important factors being ignored and pure irrelevancies substituted.

It is, perhaps, justifiable to assert that restrictions of gauge —of both rail-gauge and loading-gauge—constitute a prominent reason of existence for compound locomotives. England, France and America, the countries where railway speed is most urgently needed, are restricted, probably for ever, to the one inadequate gauge of 4 feet 8½ inches. By the irony of events, Russia and Spain, where high speeds are unknown and apparently undesired, possess a rail-gauge of about 5 feet to 5 feet 6 inches, and Ireland has one of 5 feet 3 inches. It must always be a matter of deep regret to every one interested in railways that the British standard gauge was not fixed at 5 feet 6 inches, or 6 feet; even 5 feet would give immense advantage over 4 feet 8½ inches. But that is "past praying for."

Unluckily, Britain is also hampered by a smaller loading-gauge than that available in either Europe or America, and so

locomotive expansion is curtailed in every direction but that of length, which, unfortunately, is comparatively of little value. Yet the need of augmented power, which in the non-compound engine necessarily means enlarged dimensions, has long been urgent. The proportion of "piloting," or double-engine-running, on many British lines has been inordinate, while the method is clearly both wasteful and inconvenient. In the very large ten-wheeled express engines recently brought out by Mr. J. A. F. Aspinall, on the Lancashire and Yorkshire, by Mr. Wilson Worsdell, on the North Eastern, and by Mr. Peter Drummond, on the Highland Railway, the exhaustion of the possibilities afforded by the British loading-gauge, so far as non-compound locomotives are concerned, has been closely approached.

It is manifest, therefore, that any further increment of power must be sought in the more efficient employment of existing possibilities as regards dimensions. This is where the question of compounding comes in. If increased power be sought in a mere extension of dimensions, disadvantages are encountered at every turn. Larger cylinders are useless without proportionate enlargement of boiler and fire-box, or else the engines will run themselves out of breath. These added, the result is that steam is often used wastefully and inefficiently. Increased steam-pressure is very valuable, but in a non-compound engine involves exhaust while a large potency of work still remains unemployed.

A compound locomotive, however, not merely uses the high-pressure steam to the best advantage, but also can use it a second time after it has been dismissed from its first employment, and so the same volume of steam may be said, theoretically, to do a great deal more work in a compound engine than in a non-compound. Practically, of course, the proportion of gain is modified in a material degree by the conditions of work; but a locomotive that has $13\frac{1}{2}$-inch high-pressure cylinders, as a compound, would assuredly have 20-inch cylinders, or larger, if it had to do the same duty with the two high-pressure cylinders alone.

In this connection the author may be permitted to quote from a letter addressed to him by Monsieur de Glehn, the inventor of what appears to be the most successful system of locomotive compounding yet introduced, a very clear and conclusive statement of the reasons why compounding has become necessary in modern railway circumstances. He says, "On the Continent we were continually wanted to build more and more powerful engines, being at the same time considerably limited by the weight allowed us. Bigger and more powerful boilers meant more weight; the compound principle allowed

me to use the steam more economically, and this was equivalent to having a larger boiler without more weight. I maintain that for the same total weight I can build a four-cylinder compound express, or six-coupled engine, 15 to 20 per cent. more powerful than an ordinary engine can be, having the same total weight. High pressure can be better utilised with ordinary slide-valves, for the high-pressure valves are half equilibrated, having on them the full pressure, and under them the receiver pressure; the whole work of the engine is better distributed over the whole engine, and you can give all the working parts proportionally much larger wearing surface. That it is, coupled with what I have first said about the valves, and what I say further on about the counterbalancing, which makes these engines require so little repairs in spite of the multiplication of parts and seeming complication. Increased attention is rightly being paid to the balancing of the revolving and reciprocating parts; the four-cylinder engines are far and away above all others in this respect, so long, of course, as you keep the coupling rods. Being able to work with direct steam in all the four cylinders, the starting is exceptionally certain and rapid. You see I have not said anything about fuel economy; this point is, of course, of some importance, but is generally of much less than that of power, steadiness of running, and repairs. Of course these engines are somewhat more costly to build, but not so much more as one would think at first sight, and less so than some of the simple engines (non-compound) which have been built to use high-pressure steam with Corliss or reducing valves."

When Mr. Webb brought out the engine "Experiment" he claimed, it is true, a potentiality of augmented power. But his advocacy of compounding was founded mainly on its efficiency in economising fuel consumption. He designed his compounds to be so far as possible identical with his standard non-compound type, so that the difference might consist in the compounding solely. In fact, the "Experiments" were to be simply compounded "Precedents." Similarly, when Mr. T. W. Worsdell introduced compound engines on the Great Eastern line he made them precisely similar to his standard non-compound engines in every respect except those details which belonged to compounding.

It is true that in Mr. Webb's earliest compounds there were wider differences of design from the standard type than in Mr. Worsdell's. But these were not in essential features, and most of those special differences have been abandoned in Mr. Webb's latest compounds. For instance, the non-use of coupling-rods, the driving of different axles by the high-pressure and low-pressure cylinders respectively, on which much stress was laid

in connection with the early Webb compounds, have been discarded in the latest products of the Crewe works.

It is unnecessary at this stage of the history of compound locomotives to repeat the oft-told tale of their origin and genesis. It will be more convenient to take Mr. Webb's "Experiment" as an accomplished fact and to proceed thence as a starting point in the review of the entire question. That it is no part of the programme of the present paper to enter into elaborate analyses of the various mechanisms, or to describe minutely all the details of construction, has already been made clear. It will suffice to note in general terms that in Mr. Webb's first compound, two 11½-inch—subsequently 13-inch—outside cylinders took live steam from a boiler with 1083 square feet of heating-surface and a pressure of 160 lb., the steam after driving a pair of 6 foot 6 inch trailing wheels being exhausted into a 26-inch low-pressure cylinder, placed inside the frame and under the smoke-box, which turned a single-throw crank-axle on which was placed the pair of front driving wheels, the piston stroke in each case being 24 inches. Virtually the same method of construction was repeated in the successive cases of the "Dreadnought," "Teutonic," "Greater Britain," and "John Hick" classes, with the differences of (1) larger dimensions of boilers and cylinders and increased steam pressure—viz. in all cases 175 lb., and (2) larger wheels 7 feet in diameter in the case of the "Teutonic" and "Greater Britain" classes, smaller, 6 feet in the cases of the "Dreadnought" and "John Hick" types. The "Dreadnought" and "Teutonic" engines were given 14-inch high-pressure cylinders and boilers with 1400 square feet of heating-surface; the "Greater Britain" and "John Hick" classes 15 inches; all four types having 30-inch low-pressure cylinders and the two latter having long combustion-chamber boilers with 1541 square feet of heating surface. These three-cylinder express compounds number exactly one hundred, there being thirty of the first or "Experiment" class, forty of the "Dreadnoughts," and ten each of the other three types.

It is often—indeed, commonly—assumed that the "Experiment" engines were practical failures; and this was so far the case that they were soon taken off the class of work for which they were built, and were relegated to duty of an inferior order. But special circumstances had much to do with this. It was the misfortune of those earliest compounds that they came out just on the eve of a sudden and unexpected acceleration of the express services which, as usual, brought with it a large improvement of traffic and consequent increase in the weight of the trains. Therefore, the new compounds had to face a condition of affairs for which they were not designed, and with

which they were not able to grapple. Hence their early relegation to relative obscurity, and their replacement by the larger, stronger, and swifter "Dreadnought" and "Teutonic" types.

But there were other reasons why these engines proved somewhat disappointing to their admirers. In the first place the steam pressure was only 160 lb. It has always been the author's strong opinion that compounding could not be usefully or profitably employed with express engines at so comparatively low a pressure. Practical experience has confirmed that view. Mr. Worsdell originally committed the same mistake, as the author deems it, of compounding express engines with too low a boiler pressure, viz. 160 lb. This error has been avoided in subsequent designs by both of those eminent engineers. Another drawback in the case of all Mr. Webb's three-cylinder compounds consisted in coupling-rods being dispensed with. Here again theory and experience came into conflict. Theoretically the abolition of the side-rods meant freer running, in fact, converted the engine into a double-single-wheeler which should have combined the adhesion and power of the coupled class with the easier running of the single-wheelers. And, indeed, this may have been the case in some degree. But the effect of the plan was to create two quasi-independent single-driver engines resting on one frame and supplied with steam by one boiler. It was assumed that the two engines would and must work together through their mutual interdependence, as the low-pressure cylinder which drove one of the independent pairs of wheels could not do so until it should have received the necessary steam which had been first used by the high-pressure cylinders and exhausted from them. And this doubtless was, as a rule, the case practically, as it necessarily was in theory. But long and careful observation of the actual working of these engines has convinced the author that occasionally there does come about what may be termed a lapse from absolute synchronism in the action of the high-pressure and low-pressure engines, involving a condition of affairs which may be colloquially expressed as getting out of step. In theory this possibility is so far guarded against as to be at least improbable, if not impossible. In practice it certainly appears to occur at times. It may be admitted that the evidence in this direction is mainly circumstantial or inferential—indeed, the fact is difficult to prove with scientific certainty. But the author was led to suspect its occurrence through the occasional intercalation of intervals of inferior performance in runs otherwise excellent, which lapses seemed inexplicable save on this hypothesis.

That locomotives of this type are not exempt from the tendency of all single-wheelers to imperceptible slipping, that is to

say, to the making of more revolutions per mile than would be required to cover the actual distance travelled, is almost certainly the case. Thus the wheels driven by the high-pressure cylinders would revolve more rapidly than would be necessary to cover the distance horizontally covered by the engine, which ought to be identical with the length measured by the number of wheel-circumferences represented by the revolutions. The low-pressure cylinders might not always be prepared to receive the steam exhausted by the high-pressure cylinders, as that would be excessive in case of such slipping, and so undue back-pressure would be set up. That such a possibility is presumed to be entirely guarded against does not necessarily imply that this result is invariably and infallibly attained, and the author, while fully aware of the means adopted for attaining this end, is of opinion that it is not always achieved, and that occasional non-success accounts for the few instances which have come under his notice of inferior performance when these engines have once fairly got into their stride. And it may be pointed out that the tendency, if it exist as believed, could be wholly got rid of by the simple expedient of coupling the wheels as has been done in the case of Mr. Webb's most recently built compounds.

No valid objections seem to exist to this course. Coupling has undoubtedly certain drawbacks. A high-speed locomotive runs much more freely and easily uncoupled, and is more economical alike in coal consumption and in repairs, other things be-being equal, than when the driving-wheels are coupled. For moderate loads on easy gradients hauled at very high speeds, the single-wheeler is the ideal type. Nothing can be finer than the way in which many of the single-driver engines of the Great Western, Great Eastern, Great Northern, London and North Western, Midland, and North Eastern Railways perform the class of duty best suited to their capabilities. Nor do they often fail even when put to work manifestly unsuited to their particular capabilities. But now and then they do, and it must be confessed that when set to haul heavy loads on steeper gradients than 1 in 300, especially with strong winds, drizzling rain or snow, and on a slippery rail, single-wheelers are not trustworthy. At least they cannot be relied upon to the same extent as coupled engines. Where there are two pairs of single driving-wheels the drawbacks of the single type are undoubtedly mitigated, perhaps in the case of four-cylinder non-compound locomotives almost eliminated. But when the locomotive is compound the advisableness of compelling the high-pressure and low-pressure engines to work synchronously seems clear.

Most of the former drawbacks of coupling have vanished with improvement in the construction of the side-rods, which

nowadays rarely bend or break, unless in case of some latent flaw in the material; while the fluted or I-shaped design, which many engineers were disposed to disparage when Mr. Worsdell adopted it in 1884, is now largely employed, giving, as it does, a maximum of strength combined with a minimum of weight; so that virtually the sole remaining disadvantage of coupling consists in a slight increase in the resistance due to friction. But it may fairly be argued that this drawback is greatly overbalanced by the advantage accruing, and in the case of compound engines, the advantages are undeniable. This is admitted in the most practical way by Mr. Webb, in giving his latest type of compounds coupled wheels. But the benefit would be even greater in the case of either three-cylinder or two-cylinder compounds. One advantage which assuredly would be gained is superior facility in starting, some degree of sluggishness in this respect being a weak point in the case of these, as of all compound locomotives that do not provide for the use of full steam pressure in the large cylinders at starting and in cases of special emergency.

Although it has seemed to the author more convenient to consider first the faults which might be found with the Webb express compounds, it must not be inferred that his opinion of them is unfavourable or that his experiences have been as a rule unsatisfactory. In the latter case, the fact is exactly the reverse, failure having been the exception, and consequently, as his opinions are based upon his personal experiences alone it obviously follows that these cannot be adverse. Indeed, a long and careful collation of observations in the actual work of the three-cylinder compounds shows a remarkably large proportion of favourable results. Probably the percentage of good all-round work with express trains may be said roughly to be quite as high as that given by most other locomotive types.

This does not necessarily indicate that equal results are given per unit of nominal tractive force, or of cylinder diameter, or of theoretical horse-power. It simply means that when a three-cylinder compound is set to take its turn with engines of other classes at certain duty, it usually performs its task with creditable efficiency. At any rate, such has been the experience of the author.

It is true that the earliest of these compounds, those of the "Experiment" class, were less satisfactory than their successors, for reasons already stated. But they were far from being the abject failures that prejudice led some critics to pronounce them, although they may not have been brilliant successes. The author has noted some very good runs with them. But undoubtedly they were deficient in speed, especially with heavy

loads. They could hardly have been otherwise in the circumstances. Their immediate successors, however, the "Dreadnoughts," developed great speed-capacity, as well as haulage-power, and the author has particulars of many fine runs made by them under his own observation, although occasionally they failed to sustain the usually high level of their work. Still more uniformly excellent was the running of the next type brought out by Mr. Webb, that known as the "Teutonic" class, whose most doughty representative is "Jeanie Deans," which daily ran for several years the heavy West Coast Scottish dining-car train both ways between Euston and Crewe, with singular punctuality and efficiency. Notwithstanding the diminished tractive force ostensibly given by the increase in the driving-wheel diameter by 12 inches, viz. from 6 feet to 7 feet, these engines always appeared able to pull a load quite as heavy as that which their predecessors were capable of hauling, and in some cases at a still higher speed.

They were followed by the enlarged type known as the "Greater Britain" class which retained the four 7-foot driving-wheels, and were given an additional inch of high-pressure cylinder diameter, namely, 15 inches, instead of 14 inches, while the heating-surface was increased to 1540 square feet with the aid of a combustion-chamber placed midway in the boiler-length, which itself was increased to 18 feet 6 inches. In this design both pairs of driving-wheels were placed in front of the fire-box, an additional pair of carrying-wheels supporting the rear end of the engine below the footplate. Just as these "Greater Britain" engines, of which ten were built, were an enlargement of the "Teutonic" class, so the "John Hick" type, the latest of Mr. Webb's three-cylinder compounds, was an expansion of the "Dreadnought" style. Ten also of these last-named engines were built, but so far the author has had no opportunity of testing their capabilities.

With the "Dreadnoughts," "Teutonics" and "Greater Britains," on the other hand, he has made a very large number of observations, with the general result that the locomotive work performed was of a high character, subject, however, to the drawback of frequent sluggishness in starting and an occasional intercalation of less meritorious work during the course of a long run. He is not prepared, however, to assert that in some cases this falling off might not have been due to over-anxiety on the part of the driver in the direction of fuel-economy. In the great majority of cases the work done, from whatever view-point of estimate it be regarded, was undoubtedly most excellent, and sometimes it was brilliant. Three successive runs by the "Jeanie Deans," with the up-Scottish corridor dining-

express, may be instanced as typical of this. In each case the load hauled, exclusive of engine and tender, exceeded 300 tons, and the start-to-stop speed over the run of 91½ miles from Nuneaton to Willesden averaged in each case over 53 miles an hour. The climax was reached in the taking of a load of 326 tons between these two stations in 101¾ minutes, the mean speed being, therefore, practically 54 miles an hour over a road which had virtually an equal proportion of rising and falling gradients, chiefly of 1 in 350. It has often been said that these engines might be able to haul heavy loads and ascend gradients, but were certainly deficient in speed. That has not been the author's experience. He has on more than one occasion known the 7-foot compounds of the "Teutonic" class attain speeds of 81.8 to 85.7 miles an hour on the Preston-Carlisle section of the London and North Western Railway, and engines of the "Greater Britain" type have given very similar results. There can, therefore, be no reasonable doubt that however opinions may vary as to the merits or demerits of these engines on various scores of efficiency, their capacity as to swiftness is indisputably established; and, in the author's opinion, if their driving-wheels were coupled, as are those of their successors on the London and North Western, it would be exceedingly difficult to find any weak point at all in their harness.

But apparently, although exactly one hundred of the three-cylinder express compounds have been built, the type is doomed to extinction, or at any rate to non-multiplication. It has been succeeded as the standard express type of England's premier railway by another design which, although it has been only three years in existence, has even now no fewer than fifty exponents on that line. The Queen's Diamond Jubilee year, 1897, was selected by Mr. Webb as the fit occasion of a new and important departure. This consisted in the adoption of the four-cylinder compound principle. The pioneer engine of this new order, named "Black Prince," differed in several prominent respects from its three-cylinder predecessors. The 7-foot driving-wheels and the 15-inch high-pressure cylinders were retained, as also was the outside position of the latter. But they were moved forward to a position abreast of the smoke-box and drove the front pair of driving-wheels. Instead of one 30-inch low-pressure cylinder placed inside and under the smoke-box, two low-pressure cylinders, originally 19½ inches, but subsequently 20½ inches in diameter, occupied the same position, and by means of a double crank axle, propelled the front pair of driving wheels which was coupled to the trailing pair by fluted side-rods 10 feet 7 inches in length. The

"Teutonic" boiler with 1400 square feet of heating surface was practically reverted to, but the steam pressure was increased to 200 lb. per square inch.

It will be observed, however, that the new engines discarded two characteristics which were claimed as constituting special advantages in the case of the three-cylinder engines. The latter were deemed praiseworthy because they dispensed with double-cranked axles and coupling-rods; both of these have been resumed in the case of their successors. It is not intended to imply for one moment that this latter course is in any respect unwise or objectionable. The reflection induced is rather the one that second thoughts are often best.

A wish has frequently been expressed that the compound system could undergo an adequate comparative test by being tried on the same road and in the same work alternately with a non-compound engine of dimensions which, irrespective of the compounding, would be identical. Such a comparative trial ostensibly took place on the London and North-Western Railway, when the first of the four cylinder compounds, "Black Prince," came out. But the author is unable to regard the method adopted as an adequate one for securing a really thorough comparison of the compound and non-compound systems. For while the "Teutonic" class boiler with 1400 square feet of heating surface might be employed to fill with live steam the two 15-inch high-pressure cylinders of the compound, it certainly was not capable of keeping supplied the four 15-inch cylinders of the non-compound engine which was built to run in competition. The relative failure of the latter was a foregone conclusion from the outset. For the competitive trial to be a fair one, the boiler ought to have been large enough to keep the four 15-inch cylinders of the non-compound engine adequately supplied with steam. This was not the case, and accordingly the engine, after a somewhat lengthened trial, was decisively condemned, and was converted into the four-cylinder compound "Jubilee."

An additional novelty in the design of this class consisted in placing under the leading end what would be known on other lines as a four-wheel bogie, but which on the London and North Western is entitled a double radial truck, the absence of a pivot being apparently deemed sufficient to deprive it of any right to the designation of bogie. As the term bogie has always been understood to apply to the truck upon which the leading or trailing end, or both, of an engine or vehicle is carried, without reference to the means by which it accommodates itself to a curve, whether by pivot or sliding action, or otherwise, the difference is one not quite easy to understand.

However, the point is not necessarily germane to the specific subject of the present paper, and need not be pursued further on this occasion.

As to the capabilities of Mr. Webb's four-cylinder compounds, the author, in view of his own experience, finds it impossible to entertain any doubt whatever. His first trip behind one of them definitely settled that point. "Black Prince," the pioneer of the type, took up the Scottish day express from Rugby to Willesden, 77 miles, in 83 minutes 39 seconds from start to stop, and in doing so did not run at a higher speed than 65 miles an hour down falling gradients, or at a lower rate than 50 miles an hour up the long banks of 1 in 330. The load, exclusive of engine and tender, was 244 tons, or equivalent to twenty-four south of England coaches. Such a performance alone would suffice to place the hall mark of success on the new engines, and the run was made in the ordinary course without the slightest knowledge or suspicion on the driver's part that his work was being carefully noted. As a matter of fact, the engine evidently ran quite at its ease throughout, and could have arrived several minutes earlier had the train not been already in advance of booked time.

A second experience consisted in the well-known trip of the Members of the Institution of Civil Engineers to Crewe, when the "Iron Duke," the third built of the class, took a load of 339 tons behind the tender, from Euston to Crewe, 158 miles, in 3 hours 10 minutes, in spite of signals and relaying delays amounting in all to 6 minutes, while the speed was maintained at 41, 45, and occasionally 48 miles an hour up gradients of 1 in 330 to 1 in 550, and never exceeded 72 miles an hour down the 11-mile descent approaching Crewe. But perhaps the most noteworthy feature of this run was the ease and certainty with which the four-cylinder compound attacked and climbed the rise of 1 in 70, which is encountered shortly after leaving Euston. Many of the passengers stretched their heads out of the windows and looked backward with keen curiosity to see whether any assistance were given in the rear of the train, but nothing of the sort occurred. The engine simply went straight up the bank of 1 in 70, hauling 339 tons, without the slightest hesitation or difficulty. It is impossible honestly to ignore the conclusiveness of such an illustration of the locomotive's capacity.

The return journey with the identical load was in some respects still more remarkable. The engine had to face at starting the Madeley bank 11 miles long, 3 miles being at 1 in 177 and 4 at 1 in 250, the rest 1 in 330. Up this bank with 339 tons behind the tender, the "Iron Duke" steadily main-

tained an average rate of 37·5 miles an hour, while up the later rise of 1 in 350 for 6 miles approaching Tring, the speed did not fall below 47 miles an hour; and on the falling grades it was never permitted to exceed 65 miles an hour, or even better time could have been made. As it was, the long distance of $152\frac{1}{2}$ miles without stop from Crewe to Willesden was covered with that immense load in 2 hours 53 minutes, or at the average speed of 52·8 miles an hour. All the observations were made by the author personally.

It has always appeared to the author that such performances as these must be deemed affirmatively conclusive as to the capacity of the engine, and that no subsequent failure, if such should occasionally occur, as it does with every type of locomotive, can be taken into account as against the testimony of such splendid work performed under the observation of a crowd of capable judges and independent witnesses. It is not his intention to convey the idea that he regards the type as ideally perfect, for that is by no means his view. While cordially recognising all that is admirable in the design, he does not shrink from stating that there are several points which do not commend themselves to his judgment. Among these are the comparative smallness of the boiler, and the plan of connecting all the four cylinders with a single driving axle, which, therefore, has to undergo all the drawbacks incidental to a doubly-cranked axle—viz. its inherent weakness as a column or girder—and to straight axles driven from each end, which, according to the late Mr. Stroudley, suffer from the torsional effect of alternately twisting and untwisting a fibrous structure. But while theoretical exception may be taken to these features in Mr. Webb's design, the practical result as tested by performance is, in the author's experience, unquestionable success.

Much space has been devoted to the consideration of Mr. Webb's various types of compound express engines, because they are virtually the only representatives in England of the compound system as applied to locomotives. That is to say, they are extant as standard classes employed in regular express duty, and their latest type is rapidly being multiplied by the most important railway of Great Britain. The fact is in itself sufficient justification.

It will be convenient now to turn to the other system of compounding which has been in this country the chief rival of Mr. Webb's method, and which at one time threatened to compete closely with it for the favour of the railway world.

In the year 1884, Mr. T. W. Worsdell, then Chief Mechanical Engineer of the Great Eastern Railway, constructed a

two-cylinder compound express engine on the system in which his name is now associated with that of Herr von Borries. In taking this new departure, Mr. Worsdell pursued a course diametrically opposite to that of Mr. Webb. That is to say, he did not seek to initiate any striking novelty, but endeavoured to utilise and develope an idea which had been mooted on the same railway so long ago as the year 1847. In conversation with the author, Mr. Worsdell expressly disclaimed any wish to be accredited with a novelty, and declared he was simply expanding an old idea. He also pointed out to the author that his pioneer engine of the new type was absolutely identical with his standard express class on the Great Eastern, except that one of the 18-inch high-pressure cylinders was replaced by a 26-inch low-pressure cylinder, both being kept inside the frames, while the steam from the former was transmitted to the latter instead of being exhausted into the outer air—in short, the compound principle was adopted.

One consequential difference from the standard type involved by the use of a 26-inch inside cylinder, was that a four-wheeled leading bogie had to be substituted for the single pair of radiating wheels which carried the leading end of the non-compound locomotive. Placed side by side, both cylinders drove the same crank axle. The valve-chests were placed in the smokebox, above the cylinders. Steam could be admitted direct into the low-pressure at starting by means of an intercepting valve, so that both cylinders temporarily possessed starting power, while after a stroke or two of the piston the valves were forced automatically by the exhaust steam into their normal position, and compound-working proceeded thenceforward. The results given in practice by the first engine were deemed so satisfactory that ten more were built. The author made several trips on and behind these engines in the years 1884 and 1885, and his experiences were distinctly favourable. The pioneer engine, No. 230, hauled heavy loads at a good speed up such grades as the Brentwood bank of 1 in 84 and 1 in 93, and ran with ease and swiftness on the level and downhill portions of the line.

But it appeared to the author in this case, as it did in that of Mr. Webb's earliest compounds, that the engines were seriously hampered by the limitation of their steam pressure to 160 lb., a pressure at which he cannot believe that compounding can be profitably practised in express work. Also, notwithstanding the fact that many engines of the Worsdell-von Borries type are at work on the Continent, he cannot approve the lopsided arrangement involved in having a small high-pressure cylinder on one side of the engine and a huge low-pressure cylinder on the

other. He is convinced that practically this involves some degree of unequal balance and working, nor is this opinion shaken by any theoretical demonstration, however apparently clear, that the two sides are perfectly equilibrated. This may be the case sometimes, as when an engine is freshly out of the shops, but after a while, or at occasional times, an inequality of pull and power is likely to manifest itself between the two sides, and boxing action ensues if only to a slight extent. An absolute balance and, so far as possible, identity between the two sides of a high-speed locomotive, are, in his opinion, essential factors of perfect stability.

The Great Eastern compounds did not enjoy a long career, for their author migrated to the North Eastern Railway the year after he brought out the first of their number, and his successor on the Great Eastern, Mr. James Holden, after a series of careful experiments, decided on the conversion of all the eleven compounds into non-compounds. As thus converted they are still running and doing good service.

On establishing himself at Gateshead, Mr. Worsdell at once proceeded to build a number of engines on his compounding system for the North Eastern Railway. Many of these were for goods traffic—but this should be treated as a separate branch of the subject. The compound express engines closely resembled those he had designed for the Great Eastern, but had larger boilers and smaller coupled wheels, viz. 6 feet 8 inches diameter instead of 7 feet, while in some cases the leading bogie was dispensed with and a radial axle substituted. These engines, although no longer employed on the most important express duty, have done much good service and still do so on occasion. They are sluggish starters, but have large haulage capacity, and can often develope great speed.

Mr. Worsdell then proceeded to construct ten single-driver engines with identical cylinder dimensions, but with 7-foot wheels. These too performed very efficiently. The author has known one of them maintain a speed of 30 miles an hour up the gradient of 1 in 100 approaching the Bramhope tunnel, with a load of sixteen coaches, or approximately 190 tons, and attain 79 miles an hour with the same load down a falling grade. But both of these types were soon overtaken and mastered by the rapidly augmenting train loads, and a more powerful class had to be produced.

Still adhering to the compounding principle and the single-wheeler type, Mr. Worsdell next brought out ten remarkably fine engines with two inside cylinders of the colossal dimensions of 20 by 24 and 28 by 24 respectively; driving wheels 7 feet 6 inches in diameter, and boiler pressed to 200 lb. per square

inch, 175 lb., however, being used in ordinary practice. Those engines proved remarkably efficient, hauling very heavy loads and attaining very high speeds, a rate of 85·7 miles an hour having been noted by the author, while he has seen time kept on the Anglo-Scottish express between York and Newcastle with loads exceeding 270 tons behind the tender.

It is probable that they would have continued to form the standard express type on the North Eastern but for one unfortunate drawback. The immense bulk of the low-pressure cylinders left no space inside the frames for the valve-chests. These consequently had to be placed outside, and so were exposed to extreme variations of temperature, with the consequence that they had a tendency to crack in frosty weather. This defect rendered it necessary to rebuild the engines, and as no convenient method suggested itself of overcoming the difficulty, all were converted into non-compounds by the designer's brother and successor, Mr. Wilson Worsdell, with 19 by 24 cylinders and valve chests inside the frame. Some of the coupled class were also converted, one being a very large coupled engine with 7-foot wheels, which was built by Mr. Wilson Worsdell to be identical with a new standard express class, save in having his brother's system of compounding. In this case, however, the conversion was not into a non-compound type, but into a new design of three-cylinder compound which will be referred to more fully later.

It will thus be noticed that the Worsdell-von Borries system has passed out of date on the North Eastern as on the Great Eastern, its exponent engines being simply relics of a virtually extinct method on these two lines, never intended to be revived in regular practice. It may, therefore, be fairly said that the system has been definitely abandoned on both those railways.

At this stage, instead of pausing to consider the various plans of compounding which have been experimentally and sporadically tried in Great Britain during the past fifteen years, it will be more convenient to turn to the system which although designed by an Englishman, has found practically universal adoption in France, as well as extensive acceptance in Switzerland and Germany.

So long ago as the year 1885, Monsieur A. de Glehn, Directeur-Général of the Société Alsacienne des Constructions Mécaniques, who is an Englishman by birth, designed a four-cylinder system of compounding for locomotives. It was first applied to an express engine, No. 701, belonging to the Chemin de Fer du Nord, or Northern Railway of France. That had four 6-feet 10-inch driving wheels, which were not coupled but were worked independently by two 13-inch high-pressure cylinders

placed inside, and two 18-inch low-pressure cylinders placed outside the frames, the high-pressure cylinders driving the trailing wheels and the low-pressure cylinders the middle pair of wheels. This experiment proved so successful in five years' trial that no fewer than six successive series of express engines compounded on Monsieur de Glehn's principle, were designed by Monsieur du Bousquet, the Chief Mechanical Engineer to that railway, between the years 1890 and 1898, the difference between each series and its successor consisting mainly in the continuous development of power. It is needless to describe in detail each advance in the design and construction of the admirable engines which have now become the standard type on every main line in France, a fact no less significant than remarkable, especially seeing that it is wholly ignored in Great Britain, the country of its inventor.

The locomotives constructed on the de Glehn system of compounding, although differing among themselves in details of design according to the various idiosyncrasies of the respective engineers-in-chief, may be roughly classified in two main divisions. In one the engines have four coupled driving wheels 6 feet 6 inches to 7 feet in diameter; in the other there are six coupled wheels 5 feet 6 inches to 5 feet 9 inches in diameter. In each case the engine has a leading four-wheeled bogie, two high-pressure cylinders placed outside and driving the second pair of coupled wheels, two low-pressure cylinders placed inside which drive the front coupled wheels; very large boilers with Serve tubes and large fire-box of the Belpaire type.

It will be convenient to take the latest type in each class on the Chemin de Fer du Nord as illustrations of the general principle of the design and of the methods adopted. Prior to the construction in the current year of the new ten-wheeled type of express compounds for the Paris Exhibition—one to be on show at Vincennes and the other to work on the line—all the standard eight-wheeled type on the Northern Railway, fifty in number, had 13½-inch high-pressure cylinders, 21-inch low-pressure cylinders, 25¼-inch piston stroke, and 7 feet driving-wheels with new tyres. In these respects all are alike. The gradual changes have been in the development of boiler power. Thus the total heating-surface which was 1671 square feet in Nos. 2.121 to 2.157, was enlarged to 1892 square feet in the subsequent batches, and the steam pressure which was 199 lb. per square inch in Nos. 2.121 to 2.137, was increased to 213 lb. in Nos. 2.138 to 2.180, and the grate area was simultaneously expanded from 21 to 28 square feet, while the weight in working order grew from 47 to 52 tons. The de Glehn compounds constructed for the other French main lines differ only

in minor dimensions. Those on the Chemin de Fer de l'État are practically identical. Those on the Orleans line, twenty-five in number, have slightly smaller driving wheels, 6 feet 10 inch, and slightly larger cylinders, viz. 13¾ inch high-pressure and 21½ inch low-pressure; they also have the Tenbrinck heater in the fire-box. Those of the Midi have the same sized wheels as the Nord engines, but larger cylinders, like those of the Orleans line.

The Est compounds have smaller wheels than any of the foregoing, viz. 6 feet 8 inches, but have cylinders the same size as those of the Orleans and Midi engines, also larger boilers with 1988 square feet of heating surface and higher steam pressure, viz. 228 lb., which, however has been reduced since delivery to the usual standard of 213 lb. The Ouest compounds are somewhat smaller and have 6-feet 7-inch wheels, 1440 square feet of heating surface and 199 lb. steam pressure, but the same sized cylinders as the Nord engines. The Paris-Lyon-Méditerranée line adopted the de Glehn compound system in 1891, and has steadily increased the dimensions as in the case of the Nord line, the cylinders, however, remaining always the same, viz. 13½-inch high-pressure and 24½-inch low-pressure, with 24½-inch piston stroke, while the coupled wheels have always been 6 feet 6¾ inches in diameter. But the heating-surface has been enlarged from 1594 square feet in the earlier engines of the years 1891–93—43 in number—to no less than 2040 square feet in the latest type, which came out two years ago and number as many as ninety.

One peculiarity possessed by these Paris-Lyon-Méditerranée locomotives is, in the author's opinion, the reverse of advantageous. They all have the wind-cutter fronts which some engineers so strangely believe to decrease the atmospheric resistance encountered. Thus not merely is the smoke-box front extended in a beak shape but the chimney front also is provided with an angular wind-cutter and so are the steam-dome, sand-box, and cab. That the resistance of a wind dead-ahead, or of the still atmosphere in calm weather, is to some trifling extent mitigated by this mode of construction, may at once be frankly admitted. But in reality it is so small in amount as to be practically negligible. Experiments have shown that the difference in the atmospheric resistance encountered by a flat-fronted cylindrical body and one with a pointed, or angular, or beaked, or prow-shaped front, is relatively so small as to be hardly worth providing against if such provision involve extra cost, or any other drawback.

Were no such drawback incurred even the trifling resistance which the air offers to the progress of a moving body of such

small sectional area as a train, might possibly be worth averting. But unfortunately a very serious drawback to the wind-cutter construction does exist, although it seems generally to have escaped notice. While a head wind or a still atmosphere hinders the fastest train but little, any wind in the slightest degree on one side of the course, still more if right abeam as it is nautically phrased, and most of all if on either bow—that is to say, partly ahead and partly on one side—constitutes a hindrance of a most serious nature, because by forcing the flange of every wheel on one side of the whole train against the lee rail it acts as a very powerful brake. The author has found in direct experiments that such a wind, if strong, will often reduce the speed of a fast express by 30 or even 40 per cent. Now the fatal disadvantage of the wind-cutter construction is, in the view of the author, that it exposes the greatest possible amount of surface to the most mischievous wind of all, and so increases the resistance in a very formidable degree, instead of diminishing it. It is not a little surprising that in the face of this indisputable fact the fallacious idea should still prevail that the wind-cutter front is the ideal construction type for express engines and trains. It is at least noteworthy that the best booked timings on the lines using this form of construction—which has lately been adopted also on the State Railway—are lower than on any other French line; but this is not mentioned as a case of cause and effect, being rather *post hoc* than *propter hoc*. The coincidence may nevertheless be recorded.

The engines of the six-coupled type, which are being more and more used in France, as elsewhere, on heavy express service, have 5-feet 9-inch coupled wheels, on the Nord, Est and Orleans lines; 5-feet 9-inch and 5-feet 3-inch on the Midi; 5-feet 5-inch and 4-feet 11-inch on the Paris-Lyon-Méditerranée; 5-feet 7-inch on the Ouest. The high-pressure cylinders on the Nord, Orleans, Midi, Est and Ouest railways are 13¾ inches in diameter; on the P.L.M. 13½ and 14¼ inches respectively. The low-pressure cylinders are mostly 23¼ inches, and the piston stroke, which is 25¼ in all other cases, is 25½ inches on the P.L.M. The heating surface is respectively as follows:—Nord, 1945 square feet; Ouest, 2088; Orleans, 2023; Midi, 1956; P.L.M. 1665 and 2039; Est, 2210. The steam pressure is 213 lb. in the case of the Nord, Orleans, Midi and P.L.M.; 228 lb. originally—now 213 lb.—on the Est; 199 lb. on the Ouest. The weight, in working order, ranges from 56½ tons on the Midi, to 64½ tons on the Est.

Three prominent points of merit have been instanced in the case of all these de Glehn compounds, viz.: (1) the provision for

direct admission of steam to the intermediate reservoir; (2) a three-way valve by means of which the exhaust from the high-pressure cylinder can be discharged into the atmosphere, thus avoiding an excess of back-pressure; (3) the setting of the high-pressure and low-pressure cranks on each side of the engine at an angle of 162 degrees to each other, which renders the work of starting far easier.

The author has been referred to as an enthusiast in his admiration of French engines. This is an error in terms. It is his rule never to allow any enthusiasm or feeling to enter into his view of subjects which are purely scientific and practical. He regards them from an absolutely impartial standpoint. If a bare record of the work done by the French compound engines is so striking as to compel the enthusiastic admiration of those who read it, the recorder cannot be held responsible. All the more credit belongs to the engines that do such remarkable work. When the author started upon a course of observation of the performances of the French compound locomotives he was quite unaware either that the engines or their performances were of any special merit, and on his return to England he found that this want of knowledge existed also in the case of nearly all the leading engineers of this country. It came upon him as a surprise—and not an agreeable one—to find even three years ago that engines running in considerable numbers on the French railways were doing work that engines in Great Britain had never, in the author's experience, equalled or even approached. Take, for instance, his first trip. On that occasion one of the compound express engines designed by Monsieur du Bousquet on the de Glehn four-cylinder compound system, starting from Calais with a load of 20 coaches, weighing 260 tons behind the tender, ascended the eight mile bank of 1 in 125 to Caffiers at a minimum speed of 41 miles an hour. In England he had found 36 miles an hour reckoned as a very high speed with such a load, even up a grade of 1 in 200, and here was a French engine exceeding that on a gradient nearly twice as steep!

Another revelation was the gradient profile of the French Northern Railway from Calais to Paris. It had been constantly described as a dead level throughout—as flat as a table. Yet it appeared as a matter of fact that only a length of 60 miles out of the whole 185½ was level, viz. that from Etaples to Amiens. The remainder formed four gables, the first having a continuous ascent for eight miles of 1 in 125—equal therefore to the Grayrigg bank on the London and North Western, and steeper (on the average) than either that from New Cross to Halstead on the South Eastern, or from Dover to Shepherd's Well on the

London, Chatham and Dover, which are so often quoted as obstacles to great speed on the part of the English line. Next, after a corresponding descent, came between Boulogne and Etaples, a second gable of 1 in 135 up on each side; then after Amiens an ascent of 1 in 250 to 1 in 350 for 26 miles, and a corresponding descent to Creil; finally a 13-mile climb of 1 in 200 and a similar descent. This is worse than most of the English main lines, as a comparison of gradient maps will show. Yet that one line alone can show more fast booked times than all Great Britain has at present. The Orleans and Midi lines run the Nord close in speed, but, as a rule, have lighter loads, except in the case of one express each way. The Nord line on the other hand, runs its remarkable speeds with heavy loads, yet maintains equally remarkable punctuality.

Generalisations in such matters are often misleading. It is irrelevant and useless to talk vaguely about French and English loads and grades, or to compare them as more or less steep or heavy. The author's method has been to note the working of engines with specific known loads and on specific known grades, and to make his comparisons on that basis solely. Thus, in observing the work of the four-cylinder compounds on the splendid train known as the Rome-Calais express, which was timed to run from Paris to Amiens, $81\frac{3}{4}$ miles, in 81 minutes, start-to-stop, or at an average speed of 60·5 miles an hour, he found that this was done easily within time with loads varying from 150 to 190 tons behind the tender, although two continuous banks, respectively of 1 in 200 for 13 miles, and 1 in 250 to 1 in 333 for 25 miles, had to be climbed. He found that with the heavy Lille and other expresses booked at start-to-stop speeds of 55 to 57 miles an hour those speeds were constantly maintained, and even improved upon, time being freely made up in case of station or signal delays. He found the engines able to maintain 55 miles an hour up banks of 1 in 250, hauling 270 tons, and 50 miles up 1 in 200, with a like load, each bank 13 to 25 miles in length being started at 10 or 15 miles an hour, owing to slacks for junction points. One engine maintained 43 miles an hour up the 8-mile bank of 1 in 125, hauling 280 tons. Another, starting at the foot of a 12-mile ascent of 1 in 200, with 340 tons behind the tender, attained 40 miles an hour in 2 miles and steadily gained speed until, just before the summit, the rate was 47 miles an hour; while up 1 in 250 a rate of 51 miles an hour was maintained, and that with a load of 340 tons exclusive of engine and tender. With lighter loads such as 180 to 200 tons, speeds of 60 to 62 miles an hour were maintained up 1 in 200, and with 110 to 150 tons, 65 to 70 miles an hour.

It will thus be seen that the remarkable booked speeds were accomplished through the fine work uphill, for the prescribed limit of 120 kilometres, or 74·4 miles an hour, was rigidly adhered to in downhill running, never being exceeded except on special experimental occasions and by express permission. In such particular cases the author has tested the speed up to 85 miles an hour, when the limit of the engine's capability was by no means reached; also at 75 miles an hour for many miles on the level with a light load, so that no doubt exists as to speed capacity. But it is in the actual collar work uphill and on the level that the achievements of the engines of the standard class on the Nord, and notably those numbered 2.161 to 2.180 and 3.121 to 3.170, surpassed all others in the author's experience. In no instance was a pilot or assistant engine employed.

Yet even these achievements have been eclipsed recently by one of the two Exhibition engines, specially constructed to Monsieur du Bousquet's design on the de Glehn system, for the Chemin de Fer du Nord. One of these was shown in the Vincennes Annexe, the other has run on regular services. The type differs from its predecessors in several respects besides that of augmented size. It is of the so-called "Atlantic" class, having a four-wheel leading bogie and a pair of carrying wheels behind the fire-box, the two pairs of drivers being in front of the fire-box and placed close together under the exact middle of the engine. The coupled wheels are 6 feet 9 inches in diameter instead of 7 feet. The boiler is very large, being 16 feet 8½ inches in length, or 13 feet 9½ inches between tube-plates, and 4 feet 9½ inches in internal diameter. The total heating-surface is 2275 square feet, and the steam pressure is 228 lb. per square inch. The tubes are of the Serve pattern; the fire-box is of the Belpaire design, giving 167 square feet of heating surface, with a fire-grate of 29½ square feet. The two high-pressure cylinders, placed outside, are 13½ by 25¼ inches; the two low-pressure, inside, 22 by 25¼. The cranks are set at an angle of 180 degrees instead of 162 degrees as in the earlier types. The total weight of the engine in working order is 63 tons; of the eight-wheeled tender 45 tons. The adhesion weight is 33 tons, and the total of engine and tender 108 tons.

In an experimental trip with this splendid engine, the author found it able to take a train of 305 tons, exclusive of engine and tender, from Paris to St. Quentin, 95¾ miles, in 90 minutes 52 seconds, start-to-stop, averaging 62·1 miles an hour up the 13-mile bank of 1 in 200, and never going below 59·2 miles an hour, also maintaining 75 miles an hour on the level and slight rise, all these with a load of 305 tons behind

the tender. No performance of equal merit had ever previously come under the author's notice. It should be noted that in descending down grades the speed was kept rigidly to the legal limit, 74·4 miles an hour, otherwise a still higher start-to-stop average could have been obtained.

It could hardly have been expected that such an achievement as this would have been surpassed by the same engine, but this actually happened within three weeks. The author was courteously invited by Monsieur du Bousquet to be present at a special trial of the engine, No. 2.641, with a load of no less than 365½ tons (French) or 360 English tons, which took place on the 13th October. The train selected was the famous Nord Express from Paris to Cologne, Berlin and St. Petersburg, and the test was made on its first stage, viz. to St. Quentin, a distance of about 95¾ miles, which includes one bank of 1 in 200 for 13 miles continuously and another of 1 in 333 for 10 miles. With that enormous load of 360 English tons behind the tender—or 468 tons if the weight of engine and tender were included—No. 2.641 ascended the 13 miles of 1 in 200 at an average speed of 56 miles an hour, the lowest speedpoint being 52·2, while on the latter part of the rise, the rate was as much as 57·1. On the length of level and slightly rising grades from Creil to Tergnier, a steady rate of 64 to 70 miles an hour was sustained. Tergnier, 81¾ miles from Paris, the same distance as Amiens, was passed in 80 minutes 44 seconds from the start, but thenceforward as the train had got materially in front of its booked time, although two signal checks were encountered, the driver unfortunately had to ease down, nevertheless the train came to a signal stop just outside St. Quentin station in 96 minutes 13 seconds, from Paris, the final stop inside being in 97 minutes 31 seconds, in spite of signal delays totalling 2½ minutes.

Another feat consisted in taking the Paris-Calais corridor dining train up the eight-mile bank of 1 in 125 between Calais and Boulogne at a minimum speed of 52 miles an hour, and subsequently up the 26 miles of 1 in 250 and 1 in 333 at a minimum rate of 65 miles an hour, the weight being 267 English tons behind the tender; while in the opposite direction, with a 235-ton load, the 23 miles of 1 in 250 and 1 in 333 were ascended at 65 to 68 miles an hour, and the Caffiers incline of 1 in 125 was actually climbed at an average of 61·8, the absolute minimum being 55. In a special downhill test, the engine also attained 85·8 miles an hour, so that its swiftness is unimpeachable. These achievements appear to the author so remarkable as to be almost phenomenal.

A few engines of the Vauclain four-cylinder type and also

a few of the Mallet two-cylinder compound type are at work in France, the former on the État line, but the author has had no opportunity yet of personally observing their performances. The de Glehn system, as already stated, has now become the standard for all France.

In Great Britain three experiments have been made with four-cylinder compound locomotives, built on the tandem method. One was a rebuilding of the identical North British engine which fell into the sea on the occasion of the Tay Bridge collapse. On being raised after many months' submersion, it was converted into a tandem compound, but with unsatisfactory results, so the engine was reconverted to the non-compound type. On the Great Western two locomotives were constructed on the tandem principle. Both had 7-foot coupled wheels and four cylinders, all inside, the low-pressure cylinders in each case being placed in front of the high-pressure pair. One of the engines had 14-inch high-pressure cylinders, and 22-inch low-pressure, and the other had 15-inch and 22-inch cylinders respectively. In the former case each of the low-pressure pistons had two piston-rods, one near the circumference of each piston and fixed so as to pass on either side of the high-pressure cylinders, behind which they were connected with one crosshead, as also was the low-pressure piston-rod. Thus each crosshead was actuated by three piston-rods, and the engine had six piston-rods altogether. The experiment was interesting but not successful, and the engines were condemned.

A somewhat similar arrrangement is used on twenty eight-wheel coupled goods engines of the Chemin de Fer du Nord which are built on the tandem four-cylinder compound principle, and which are stated to do very efficient work. One three-cylinder compound engine with six coupled wheels and a radial leading-axle has also been tried on the Nord line. In this case there is one high-pressure cylinder inside and the two low-pressure cylinders are placed outside the frames. No particulars of this engine's work have so far been procurable.

Two isolated types of three-cylinder compounds have also been tried by British designers. One case is that of a North Eastern 7-foot coupled express engine built on the Worsdell-von Borries system. This has been rebuilt as a three-cylinder compound with a single 19 by 26 high-pressure cylinder inside and two 20 by 24 low-pressure cylinders outside. In several experimental trips, the author found it do excellent work, pulling heavy loads and attaining high speeds, but the type has not been multiplied. The other instance, although emanating from a British designer, Mr. John Riekie, Chief Mechanical

Engineer of the East Coast of India Railway, and tried in British territory, viz. in India, has not yet been seen in the mother country. Mr. Riekie's system consists in retaining the two full-sized high-pressure cylinders of a non-compound engine, and adding a third, or low-pressure cylinder, these cylinders acting on three cranks set at angles of 120 degrees. The ratio of the combined area of the two high-pressure cylinders is to the low-pressure cylinders as 1 to $1\frac{1}{4}$, instead of 1 to 2 or $2\frac{1}{4}$ as in the case of most other compound types. One great difference between this system and all its predecessors consists in cutting off steam early in the two high-pressure cylinders, in place of a late cut-off in one or two smaller high-pressure cylinders, also in adopting a new departure in low-pressure cylinder ratio to suit this early cut-off. The cranks are so balanced that all revolving parts are balanced in a vertical plane. The inventor claims that both a wider range of expansion is obtained by his method, and also that a greater reserve of power is retained. He contends that he gains 30 per cent. more power by his plan; that it is capable of modification so as to give 60 per cent. more power than the largest that can be got out of cylinders with existing methods; and that owing to the possibility of vast increase in cylinder dimensions, larger driving-wheels could be used and piston speed thus be diminished. According to the records taken of the performances by two Indian engines constructed upon this system, it appears to be very efficient in operation and to possess much promise of future success. It is to be wished that it should have a fair trial in this country, but as the author has had no personal experience of its work, he is, of course, unable to offer any definite opinion, save on theoretical grounds, as to its value, which he is disposed to rate highly.

Summing up, in conclusion, the results to which the author has been conducted by his fifteen years' personal observations of the working of compound locomotives, he feels no hesitation in declaring that the four-cylinder compound must almost of necessity be the standard locomotive of the future in Great Britain, as it is of the present in France. He is not entirely satisfied that the limit of extension permitted by the British loading-gauge has yet been reached in the case of simple high-pressure or non-compound engines, even by Mr. J. A. F. Aspinall's Lancashire and Yorkshire giants of the 1400 class, or by Mr. Wilson Worsdell's ten-wheeled 2001 type. Smaller wheels than 7 feet 3 inches in the former case and larger boilers in the latter would permit yet further increment of power were this deemed desirable, but it is questionable if that could be accomplished with economic advantage. On the other hand, compounding enables

the same steam to be profitably used twice over, and also to be first employed at a higher pressure than would be economical were it to be exhausted after doing duty but once. In this way large economy of power can be obtained, consequently more power out of a given quantity of steam and of the material consumed in its generation and within limited dimensions. But to attain these results in the largest degree, the author holds it essential that four cylinders should be employed with ability to use high pressure in all four cylinders at starting or in case of emergency—as in the de Glehn compounds—and that the driving-wheels should be coupled.

As to the relative merits of the various cylinder positions or of the several rival systems of four-cylinder compounding, the author does not consider it needful to express any opinion. He has deemed it preferable to record his own experiences with the systems used in England and France, and to indicate the conclusions to which those experiences have conducted him.

The question has been treated mainly in reference to what is, perhaps, the most important department of locomotive duty —the haulage of heavy express trains. But it may be added that the profitable employment of compound locomotives appears to be virtually limited to that class of service and to goods traffic having long runs without stop. In the latter class of work Mr. Webb and Mr. Worsdell have for some years employed very powerful compound goods engines, and, it is stated, with distinct advantage, while Monsieur du Bousquet's compound goods engines on the Chemin de fer du Nord and his ten-wheeled de Glehn compounds of the 3.121 class for fast goods trains have done excellent service, one of the latter having hauled a train of 1014 tons at 38·5 miles an hour on the level and slightly rising gradients, at 21·1 miles an hour up 1 in 200, and at 23·4 miles an hour up 1 in 333; also 876 tons at 26·6 miles an hour for 23 miles up a grade of 1 in 200. But in this department of traffic the author has had smaller experience with compound engines and he therefore prefers to say little on the subject as he cannot speak with full personal knowledge. The application of compounding to engines working trains that have frequent stops, he entirely disapproves, and the experiments tried by Mr. Webb in this direction have apparently justified that unfavourable opinion. The true function of compound locomotives is to take trains that run long distances without stoppage.

It may reasonably have been anticipated that the author would touch on the important questions of relative fuel consumption and relative cost of repairs in compound engines as

compared with the non-compound types. He has not done so for the simple reason that no information is available that appears to him satisfactorily conclusive. He was a deeply interested and, he might add, highly amused, listener to the animated discussion which took place on this head among some of the most eminent of British engineers at last year's conference of the Institution of Civil Engineers. In view of the amazingly discrepant, utterly contradictory, and wholly irreconcilable statistics put forward on that occasion by some of the most distinguished authorities, he prefers not to be citable as being among those who "rush in where angels fear to tread."

DISCUSSION.

The CHAIRMAN said that, although he was not a locomotive engineer, he had followed with great interest the discussion on compound locomotives which had been going on for many years. He could not express an opinion which would weigh either on one side or the other; but he was exceedingly glad that the Society had been honoured by there having been read before them a paper by Mr. Rous-Marten, which summed up the subject in a most useful and just manner. He admired the unbiassed way in which the author had brought the subject before them. The author had dealt fairly with the facts which he had had to face. To his (the speaker's) mind the facts which Mr. Rous-Marten had brought before them seemed very conclusive. It appeared to him that it would be very difficult to controvert the astonishing fact that French engineers seemed to be running compound locomotives at very much greater speeds than English engineers were running them. It appeared that, given a proper sized boiler and a fair amount of heating surface, and cylinders properly designed as to area, there should be no difficulty in making compound engines a great success. Personally, he always liked to use steam twice over in any engines which he had to work. It seemed to be an undesirable thing to spend money in heating steam to a high temperature only to use it in one cylinder and then let it blow away into the atmosphere, or only use it for heating water. He preferred to get work out of steam before discharging it. The interest taken in the subject of the paper was evidenced by the fact that Mr. Webb of the London and North Western Railway, Mr. Holden of the Great Eastern Railway, and several other English locomotive engineers, as well as five engineers of the leading French railways, had written expressing their regret at being unable to be present at this meeting.

The Chairman then moved a cordial vote of thanks to Mr. Rous-Marten for his paper, which was unanimously carried.

Mr. Norman D. Macdonald said that there was one point in the paper which he should like to correct, as it seemed to be a mistake. The author stated that the rail-gauge in Russia was 5 feet 6 in. He thought that India was in the author's mind instead of Russia, for the gauge in Russia was only 5 feet. There was also a further point which called for remark. The author said, "In this connection the author may be permitted to quote from a letter addressed by him to Monsieur de Glehn, the inventor of what appeared to be the most successful system of locomotive compounding yet introduced." He supposed that the author had not passed over the extraordinary work done by the Vauclain system of compounding in America. Probably he was dealing purely with what he had himself seen, and he had mentioned in passing that there were some Vauclain compounds on the state railways in France. In 'The Times' of this morning there was an analysis of the running of Vauclain compounds in very fast and heavy services on a run of 55½ miles, booked in fifty minutes start to stop, showing extraordinary work over a period of eleven weeks. There were hundreds of Vauclain compounds in America and elsewhere doing good work in both passenger and goods traffic. In the foregoing quoted remark, the author had rather, it seemed, passed over the Von Borries two-cylinder compound. No doubt that engine had disappeared from this country, but it was still largely used on the Continent, and especially in Prussia.

Mr. Macdonald then detailed some excellent work he had done with them when crossing Prussia *en route* to and from St. Petersburg in the Nord Express, weighing 290 tons, when a great deal of lost time was made up in spite of gales and snow.

As to the future of locomotives in this country, he agreed with the author that the limit had not been nearly reached in the size of boilers and fire-boxes, provided that the driving-wheels were not made too large. He urged the use of the largest possible boiler for economy and efficiency; in his view the cylinders in this country were often too large for the boiler. One difficulty which he (Mr. Macdonald) foresaw was that of the driver not seeing where he was going if there was a very large firebox, but in the Paris Exhibition he saw there were two possibilities opened out. Among the Creuzot exhibits was the huge Schneider locomotive, on which the driver was placed in front in a sort of private cabin on a large bogie platform having a sort of prow with ample windows, giving an excellent view. The driver was 44 feet from the stokers, who supplied the coal

to the enormous boiler by two stoke-holes. There was a speaking tube and gong communication between the driver and the stokers, so that he could communicate with them.

Another plan was seen, at Vincennes, in the very large Italian compound six-coupled express engine, which was, as it were, a bogie-engine with the boiler turned round. The boiler was put on the opposite way, with the funnel to the rear, and the driver stood looking out in front with his back to the fire-box, and with a perfect view of the line from the windows in the prow which enclosed the footplate. In short, the position of the driver was the same as in a tank-engine running bunker first, except that he had his levers, etc., in front of him. On engines designed as these two were, the designer could put a boiler or fire-box made so as just to fit the tunnels without fear of obstructing the driver's view. In both types the driver had a much better view of the line than it was possible to get from even the small, old-fashioned engines which were used in Great Britain.

He saw no reason why they should not have compound engines in this country with over 2500 feet of heating surface, 230 lb. of steam and six-coupled driving-wheels, if they kept the wheels down to 5 feet 10 inches, for with the moderate wheel they would be able to start quickly and maintain a high speed up inclines. What was wanted was power to get a good speed up inclines and maintain a high average, such as was aimed at in France and America, and to take trains of paying load at speeds adequate to develop the traffic. The question of large driving wheels was not so important as it was supposed to be in this country. To get into speed quickly was very important in express work, for if so many minutes were occupied with the first few miles it followed that so much less time was left for the balance, and to keep time a very high speed would need to be maintained for part of the run to make up for the slow start, or slow running uphill.

For level lines like the London and North Western, and Midland (southern sections), the Great Northern, the Great Western, etc., he advocated a ten-wheeled engine also, but of the 'Atlantic' type, such as the New Nord locomotive, No. 990 Great Northern Railway, 1400 Lancashire and Yorkshire Railway, etc., because a driving wheel of 6 feet to 6 feet 6 inches might be used there, where the adhesion of a ten-wheeler was not so necessary.

The same idea applied where the trains were always light, as in the Manchester-Liverpool, Edinburgh-Glasgow services, provided always they had no cramping of boilers by wheels.

British engineers might have to consider again the question

of four-cylinder tandem compound engines, because their small clearance gauge hampered them in placing large low-pressure cylinders outside, or in adopting the Vauclain system. The tandems were most successful in Russia, and he had seen them used there in large numbers and of great size, both for express work and for goods work.

One difficulty which he foresaw in the use of engines of the Vauclain type in this country was that the grouping of the cylinders outside might render them too big to run past the platforms; but the large cylinders might be got outside by being put tandem-wise. Russia was a very practical country from an engineering point of view, and it was going in for compounds on both the tandem and Vauclain systems. He had that day received a letter from Messrs. Baldwin and Company, of Philadelphia, saying that they saw no reason why they should not be able to modify the design of four-cylinder Vauclain compound engines so as to run in Great Britain. There was a good hope that they might get one over to be tried on a British railway. He had been speaking mainly of express locomotives, but his remarks applied to goods engines also, except that with smaller wheels we could hope for still larger boilers.

Mr. ALLISON SMITH said that Mr. Rous-Marten was a very cautious man, and had studied the subject of fast locomotive running more than any man that he (Mr. Smith) was acquainted with. He was very pleased to find that Mr. Rous-Marten's conclusions were so sound. He (the speaker) had been for many years in Australia and New Zealand, and in those countries they had not yet arrived at compound engines, and he had not had the advantage of seeing many compound engines in this country. There was not much doubt that what was really wanted was an engine which would take the hills. In Australia and New Zealand the ruling gradient was 1 in 50, and there was a great deal of it, and wheels of 6 feet diameter were the largest that could be used. They often reached speeds of 75 miles an hour with a 6-feet wheel on the level, and they thought nothing of running at over 60 miles an hour with 4-feet 6-inch wheels. That was a performance which he thought was not realised in this country. Sometimes in New Zealand he had run at the rate of 57 miles an hour with a 4-feet wheel and a four-coupled engine on the 3-feet 6-inch gauge, and over 50-lb. metals.

There was no doubt in his mind that great improvements ought to be made in the haulage power of the engines of this country. Since his return a year ago, he had travelled about a good deal, and he had found a very large amount of double banking. It was equivalent to putting two horses to do the work which ought to be done by one horse; and in too many

cases this was done simply because there were perhaps 25 or 30 tons more than one engine could pull. For the sake of this small extra weight a second engine was put on, and the cost of the locomotive power was doubled. He had no doubt that better dividends would be obtained if points of that kind were properly studied.

Mr. W. M. Acworth asked Mr. Rous-Marten whether he was prepared to entirely justify the following passage in his paper: "The application of compounding to engines working trains that have frequent stops, he entirely disapproves, and the experiments tried by Mr. Webb in this direction have apparently justified that unfavourable opinion. The true function of compound locomotives is to take trains that run long distances without stoppage." Mr. Webb's compounds were not as other peoples' compounds, and it was a strong statement to say that it was perfectly clear that compounds would not do for a frequently stopping service. He (the speaker) would not venture to express an opinion of his own, but he had travelled thousands of miles in America, and there were very few trains in America which did not stop every few miles to get over a crossing or for some other purpose. Three engines out of five built by the Americans were compound, and they were used for stopping work. He therefore thought that the opinion expressed by Mr. Rous-Marten was too strong. The author spoke of a Vauclain compound travelling 55 miles in 50 minutes. About a year ago, he (Mr. Acworth) travelled in one of those trains a distance of 54 miles in 45 minutes. That was a performance which he thought would not often be beaten even by Mr. de Glehn's compounds.

It was the commonest thing in the world, when outsiders ventured to say that English engines did not do the work they ought to do, to reply that the English gauge was very restricted. And of course the huge American locomotives could not run in England. He would ask Mr. Rous-Marten if it was a fact that the Nord 10-wheel compounds could run inside the loading-gauge of any English railway.

The second question was this: France and America both ran heavier trains at higher speeds than England did, and those countries were practically committed to compounds. What was there in England which made compounds unsuitable for England? It seemed to him that that was the way in which the question should be put to a scientific engineer. What was the peculiarity in England which made it inexpedient to build compounds for England? It was not asserted that compounds were more extravagant in coal. If there was any difference it would be admitted that they were cheaper. Coal cost at least

twice as much on the tender in England as in America. As to water, compounds admittedly saved water, and apart from its cost, which was not inconsiderable, either very big tenders must be built, or track tanks must be provided, or there must be extra stoppages, if more water was used up for a given amount of force in non-compounds than in compounds. That seemed to be certain.

There was another point of great interest. There was an engine which had become a standard type on every railway in France. Just fancy a standard type engine for England!

The third question was still more important. The immense increase of power in France was all in the boiler. Everything else remained more than stationary. On the Ouest they had begun with less heating surface than on the Nord, and larger cylinders, but because they had simultaneously reduced their cylinders and enlarged their boilers on the Nord railway, they had actually reduced the size of the cylinders in the last and most extraordinarily powerful engines, but they had put 200 or 300 feet extra on to the heating surface. A more startling contrast to English methods he had never come across. Did Mr. Rous-Marten think that English engines could take more than 180 tons if they cut down their cylinders and enlarged their boilers?

Mr. W. P. Morison said that the impression conveyed by the paper was, that the French express train service was vastly superior to the service in this country. The fastest French train which he could find in Bradshaw was that from Calais to Paris. The distance was 185½ miles, and the train reached Paris in 3½ hours. The rate was 53 miles an hour. In England two trains a day were running from London to York, a distance of 188 miles, at the rate of 52¼ miles an hour. The time was 3 hours and 35 minutes, including a stop of 4 minutes. If the stop of 4 minutes were eliminated, the average speed would be 53·7 miles an hour. It had been stated by Mr. F. C. Marshall, that a train performed the journey of 540 miles from London to Aberdeen, at an average speed of 64 miles an hour. The fastest train running in England was, he believed, the Flying Dutchman, from Paddington to Bristol, a distance of 118½ miles. It left Paddington at 10.35 and reached Bristol at 12.50. The average speed was 52¾ miles per hour. The London to Exeter train ran, until August, 194 miles without stopping, at an average speed of 52 miles an hour. That was, he believed, the longest run in England without a stop. The time had been altered recently for the winter service. He supposed that English locomotive engineers designed their engines to meet the exigencies of the traffic, and with a view to economical

working. Economy was, in their minds, a very great consideration, the coal bill being an important question. The instances which he had quoted showed that English locomotives attained a high speed. The most recent coupled express engines of the Scotch lines and the North Eastern were doing excellent work.

Mr. W. B. THOMPSON said that one point had occurred to him, with regard to Mr. Riekie's compound engines. The steam was taken where in the ordinary non-compound engine it would be discharged into the atmosphere, and it then went into a further cylinder where it was expanded to a still lower pressure. He did not quite see how a sufficient blast was got to keep the fire going.

Mr. A. G. ROBINS said that it appeared to him that in locomotive engines, both France and America were a long way ahead of England. Englishmen ought to try to bring themselves to a somewhat higher standard. The question of high speeds was only one point in the very much greater question of commercial supremacy, and in that larger question England was falling behind. In the matter of locomotives the criterion of supremacy was speed. Speed apologists had dealt with the question simply from the point of view of £ s. d. Managers and locomotive superintendents had said that it did not pay to run at high speeds; but he wished that they would realise that it was not simply a question of money, and that the raising of the standard in one essential point would tend to raise the standard of excellence all round. If the speed of the locomotives of the best trains was raised there would be a raising of the speed of the whole line, and of the standard of the whole line. That was a great point to be remembered.

Mr. R. ST. GEORGE MOORE said that the last time he was in Belgium he saw an English type of locomotive taking one of the international through trains out of Ostend Station. He was under the impression that it was a British-built engine of the Caledonian type, and he should like information as to how it had worked in comparison with Continental-built locomotives on the same road.

The Rev. W. J. SCOTT said that one or two of the speakers had asked very reasonably how it was that if compound engines had given such very good results in France and in the United States they had been so very little used in Great Britain. He was afraid that the reason was to be found in the attitude of mind of English locomotive engineers, and as long as that state of things remained England would be left behind. He would say to all those who dealt with the speed of trains, "Put not your trust in Bradshaw." Even the companies' own public time-tables might be very misleading; but Bradshaw might be

trusted to mislead. Nobody ought to venture to write about train speeds or to discuss them unless he had access to the working or service books of the respective companies. Many Continental trains, for example, stopped for water, although there was no stoppage marked in the time-tables. The stoppage, of course, made a difference in the actual time of running. The direct train to Exeter ran from Paddington at 10.35 only in summer, and was suspended during the winter. In the case of the Great Western line the time of their fastest trains in almost every instance differed from the times given in the time books, and the actual speed could only be got from the service books. He thought it was quite clear that unless all English express trains were to be run uniformly double-headed, there must be some radical change in the building of the engines. The trains became heavier and heavier, and even the heaviest trains in this country would be reckoned as light in America. He believed that the only possible way of dealing with the increasing weight would be the introduction of some form of compound engines, unless some new force was brought into play.

Mr. Edgar Worthington said that it seemed a pity to confine such a long and interesting paper to what was now being done in England and France, which precluded any reference being made to the successful working of the Worsdell type of two-cylinder compounds in Germany, South America, Portugal, and other countries, including Ireland, where the Belfast and Northern Counties and other railways had been so much benefited by their introduction for both goods and passenger service. The author had also refrained from mentioning the valuable experience with two, three, and four cylinder compounds in the United States, where that class of locomotive met with little favour until it burst into popularity about the year 1889. The Gölsdorf system, which was so readily applied and developed in Austria, was also worthy of attention. He therefore thought that the comparisons of the two, three and four cylinder compounds, made by the author, and his references to the first system being practically extinct in England were calculated to mislead, and further that this comparison of engines so widely differing in size was one of heating surfaces rather than of the comparative merits of the numerous systems of compounding.

Mr. Rous-Marten, in replying upon the discussion, said that he would reply to the last speaker first, and he must apologise most sincerely for inflicting another grievance on Ireland; but the terms of his paper, 'Notes on English and French Compound Locomotives," excluded the sister isle. He was not ignorant of the fact that compounding had been carried on in Ireland, but he had not had any experience of the practice in

that country. He had been so specific in the title of his paper that it surprised him to hear several speakers complain that he had not referred to the work of the Vauclain compounds, or to the work of tandem compound engines in Russia and Germany and elsewhere. He had expressly said that his remarks were confined to England and France. He should like to ask those present to what length his paper would have reached if he had extended his observations all over Russia and Prussia, Austria and Ireland. He was fully aware of what had been done with the Vauclain compounds. There were several of them on the State Railway of France, but that railway had the lowest speed of any French line. He hoped that Mr. Worthington and other speakers would acquit him of doing any intentional injustice.

As to the remarks made by Mr. Morison, he certainly listened to them with very great surprise. Mr. Morison spoke about one of the French trains, that from Calais to Paris, which he said performed the journey without stop in three hours and a half, that being at the rate of 53 miles an hour. In the official time-table that train was booked to stop six minutes at Abbeville for water. In his experience the train had always run well within time, although it took a load of 230 to 270 tons. The Nord express trains which he had referred to were regular trains running in the ordinary service, and not specials running on experimental trials. There was a load of 305 tons in one case and 360 tons in the other, behind the tender. As to the Great Western train supposed to run to Bristol in two hours, he imagined that there must be some mistake. The train was never timed to run in less than two hours and a quarter, and it had a difficulty in doing the journey in that time.

Mr. Thompson had asked for some further information about the system of Mr. Riekie, but he (the author) was afraid that he could not give it. Mr. Riekie had been good enough to call on him and show him some diagrams, and had promised to call again before the paper was read, but had not done so nor given him any further information.

Mr. Moore had referred to the Caledonian engines used in Belgium. Those engines were ordered by the State Railway of Belgium upon a report which he (Mr. Rous-Marten) made on them, and which was published in the Bulletin of the International Railway Congress. The Belgian State Railway Department instructed Mr. M'Intosh, the Engineer-in-Chief of the Caledonian Railway, to design five engines of that class, and those engines were now running on the Belgian State Railway. They had given absolute satisfaction to everybody. Mr. M'Intosh went over to Brussels last year to examine the engines

and he went from Ostend to Brussels with one of them, but he was so much dissatisfied at the horribly slow speed at which they were allowed to run that he did not wish to see any more of them. The engines were still running in Belgium and doing very well, but Belgian speed was strictly limited to 56 miles an hour.

Mr. Macdonald had expressed surprise that he (the author) had not referred more fully to the Vauclain and tandem compound. There again his answer was that he had been referring to France and England, and the Vauclain had not entered into the French or English practice, except to the small extent mentioned in his paper. The Worsdell-von Borries system was practically extinct in England. As to the tandem compounds he had said all about them that could be said as to their use in England. He knew that a very large amount of secrecy had been observed about even the dimensions of those tried on the Great Western, and he had had very great difficulty in getting the curious information which he had mentioned in regard to them. As to the Russian tandem-compounds he had no experience with them, but he, like other people, was struck with the gigantic Russian compound at Vincennes, which stood nearly 17 feet high above the rails.

As to the question of the Vauclain engines not being able to clear the British platforms or bridges, some of those present might perhaps have been at the meeting of the Institution of Civil Engineers last year which had been mentioned in connection with coal consumption. Mr. Webb read a paper as to compound engines, and an American engineer present said that an engine which his firm had built should be run against Mr. Webb's engine. Mr. Webb replied that the American engine could not pass through a single bridge or tunnel on the North-Western system, as it was too high for the tunnels and bridges and too broad for the stations. The American replied, "Never mind; we will chance all that." That was very enterprising, but it was scarcely "practical politics."

He valued the remarks of Mr. Allison Smith, who was the first locomotive superintendent of the principal railways in New Zealand. He designed most of the locomotive systems there, and did admirable work at the headquarters near Christchurch. Subsequently he was promoted to the higher sphere of Victoria, where he organised an admirable system, which, when he (the author) was out there in 1893, he had inspected with great interest. Since then Mr. Allison Smith had organised and designed locomotive works in various other colonies.

Mr. Acworth had referred to his (the author's) remark that he considered compound engines unsuitable for stopping trains,

and, if he understood Mr. Acworth rightly, he also said that a large number of compound engines worked stopping trains in America. His (the author's) answer to that must be that as his references had been entirely to French and English compounds, and as his experience had been in France and England, he could hardly be censured for not going into the subject as regarded America. He thought there was no doubt that the consensus of opinion among English and French engineers was that compounds were not suitable for short distances and stopping trains. When he made that statement he had specially in his mind a remark made by Mr. Aspinall to the same effect. He had waited more than fourteen years before venturing to express a definite opinion as to the value of compounding for locomotives, and the opinion he now offered was based solely on his own experiences. His experiences of compound engines for short distances had been distinctly unfavourable. They had not done well on that class of work in England and France; but he was quite prepared to hear that they had done better in other cases. He could only speak of what he knew. Mr. de Glehn, in answer to a question which he (the author) put to him a year ago, said that there was nothing to prevent his compound engines from being built to the English loading gauge, and being as efficient in England as they were in France. He put that point specially to Mr. de Glehn, and, after checking the dimensions so far as he could, Mr. de Glehn was most distinct in giving him that information. He went even farther and said, "I have never yet built my compounds in such a way that I should require even to use the full English loading gauge."

Mr. Acworth had asked why compound engines should not do as well in England as in America. That was an absolute poser. He (Mr. Rous-Marten) had never been able to see any reason why not. He had talked with nearly every locomotive superintendent in England, and he knew that privately one or two were making experiments, but it seemed to him that they might spare themselves the trouble when they had only to go across the Channel and get the locomotive designed by Mr. de Glehn. So far as his experience went he had not come across any system yet that commended itself to him or to the French engineers as did the de Glehn, if he might judge the tree by its fruit. He heartily agreed with what Mr. Acworth said about the importance of increased boiler power and augmented pressure. He had been preaching to that effect for years, and he ventured to hope that he had done so with some good result.

There was no doubt that they were rapidly approaching a

sort of deadlock in their railway system. On some railways they were getting to a point at which, as one speaker remarked, it seemed to be a duty to pilot every train. A train that had two engines to it must be regarded as two trains, so far as locomotive power was concerned. It was merely a variant of a divided train. At the Paris Congress there was a report on the North Western Railway in which it was said that on the Preston and Carlisle section there was practically no piloting at all. He asked a friend to take notes for him one day at Carlisle of the expresses that went through, and the friend recorded ten expresses. Out of those ten expresses ten were piloted, and yet it was said that on that line there was practically no piloting. Of course he could say something about other lines in the way of piloting did time permit. But if a pilot was used on French lines the speed was limited to about 30 miles an hour. On the French Northern line a pilot must not be run at all on an express train. When a pilot was used the speed of the train had to be reduced. The running of a pilot engine to increase speed was absolutely unknown in France. He would say in virtue of his own observations that the French had been able with their compound engines to produce results which he regretted to say he had never seen equalled in this country. He hoped that the time might come when equally good results would be produced here; but it had not come yet.

The following communication was received from Mr. E. L. Ahrons, but, owing to the lateness of the hour, it had to be taken as read.

I very much regret that I am unable to attend personally and speak on Mr. Rous-Marten's paper, I therefore beg to submit the following remarks thereon.

The history of compound locomotives in Britain appears to me divisible into two distinct periods, the first, from 1882 to about 1892, when economy of fuel was the chief object which certain locomotive engineers attempted to obtain; and the second period, begun only in 1897, and still in its infancy, in which economy of power is the desired end. Compound engines during the first period cannot be said to have been a very great success, although perhaps it would not be fair to say that, taken as a whole, they were a failure. The author of the paper distinctly avoids the question of fuel consumption, on the perfectly true grounds that conclusive information has not been published. But it appears none the less certain that if there had been any striking economy, the whole of the railway engineering world would have heard of it, and moreover have

had proofs of it furnished. It is true that a fuel economy of 15 per cent. has been claimed for the compound system. Like the author of the paper, I am without the necessary information on this branch of the subject, but I find on examining some coal sheets of 1884-5 that the London and North Western Railway three-cylinder compounds at that time were burning some 5 to 7 lb. per mile more than simple engines of similar size on other railways, the latter doing if anything the harder work.

Turning to the North Eastern two-cylinder compounds, one point that has always struck me is the harshness of the blast. I have often watched these engines labouring up a bank with trains of about 150 tons, and making a noise that could have been heard more than a mile away, whereas the simple engines, which the compounds were designed to replace, working under similar conditions, would come up easily and comparatively noiselessly. The engines should not have been overpowered by the load, but they were certainly being thrashed, and were exhausting at too high a terminal pressure. The advantage claimed for these compound locomotives, that the low-pressure exhaust reduces the pull of the blast on the fire, has often appeared to me to be absent in practice, and although in the two-cylinder and three-cylinder types there are two beats instead of four, these beats appear to have more bad effect on the fire than should be the case.

I think that the author's expression, "The same volume of steam may be said, theoretically, to do a great deal more work in a compound engine than in a simple one," is somewhat apt to mislead. One pound weight of steam at a given pressure can do only a certain amount of work, whether that pound be expanded in one or in four cylinders. Theoretically, a simple engine should get more work out of each pound of steam than a compound engine, for in the former there is no drop of pressure in the intermediate receiver or pipes between the high-pressure and the low-pressure cylinders, which drop of pressure is an absolute loss. On the other hand, there is less variation of temperature in the cylinders of the compound engine, and it is this variation between the initial and the final temperatures of the steam as it enters and leaves the cylinder that is the chief *raison d'être* for compounding in general. If steam at 175 lb. pressure per square inch be admitted to the cylinder of a simple locomotive, its initial temperature is about 376° F., and if it could be expanded down to 10 lb. per square inch, the final temperature would be 240° F., so that at each stroke of the piston the temperature would vary through a range of 136°.

It results that the entering steam is partially condensed, and the resulting vapour uselessly re-evaporated towards the latter end of the stroke. If, however, the same steam be used in the high-pressure and low-pressure cylinders of a compound engine, the variation of temperature in each cylinder could be made not to exceed 68° F., supposing that no loss of pressure had taken place in the receiver.

This variation must, however, take place much more in slowly moving goods engines with low piston speeds of 400 to 500 feet per minute, than in fast express engines, with high piston speeds of 1000 to 1200 feet per minute, and this has always led me to think it remarkable that, when applying the compound principle to effect fuel economy, English locomotive engineers began at the wrong end by compounding their express engines, and only thinking of the goods engines afterwards. That there is very little economy to be gained with compound passenger engines appears to be proved by the fact that many South American and other foreign lines, which applied the two and three-cylinder compound principles some ten or twelve years ago, have now discarded them. And in these countries, where the normal price of coal is about 2*l*. per ton, economy is of vital importance.

The above remarks are intended to apply rather to the compounding period as it was, than to the present-day necessity of obtaining increased power regardless of fuel economy. This is quite a different question, and may be said to have come to the front owing to the lack of a satisfactory valve gear for simple engines. With the usual forms of valve gear it is impossible to obtain good results if the steam is cut off at less than 25 to 30 per cent. of the stroke. As the engine is notched up and the travel of the valve decreases, the exhaust opens later and closes earlier, and considerable back pressure is the result. But if a smaller high-pressure cylinder be employed, the same volume of steam can be admitted to it, the cut-off takes place later, so that the exhaust will close later during the return stroke, and the engine will rid itself of the steam more easily.

It has been attempted in France to use a modified Corliss gear, with independent admission and exhaust valves, for simple locomotives, in order to overcome the above difficulty, but the complication of parts is so great as to seriously detract from the value of the gear. If it were possible to design a simple and reliable valve gear, without such complications, which would allow of cutting off at 10 or 15 per cent. in a large cylinder of a non-compound locomotive, there would be no need for the four-cylinder compound, which is of necessity

destined to be the locomotive of the future for express service. The simple engine would then be able to cut-off the steam early enough to avoid running itself out of breath.

All compound locomotives have one drawback inherent to compounding: they cannot adapt themselves like the simple engine to both heavy and light loads. Unlike the marine engine, which works under a constant load, the locomotive may have to work a very heavy down train, and return with a light up train, and if it has been designed for the former work, it is generally a wasteful machine when put to the latter work. The best results in a compound are best attained, theoretically, when the cut-off in the low-pressure cylinder is such that the volume of steam admitted to that cylinder is equal to the capacity of the high-pressure cylinder. In practice some variation from this is made to equalise the powers given off by the two cylinders for the designed load and speed, but it has much more to be varied in actual working, to suit the heavy and light loads that have to be hauled in accordance with traffic requirements, with considerable loss of efficiency.

I believe at one time the London and North Western three-cylinder compounds were worked so as to vary the cut-off in the high-pressure cylinder and run the low-pressure cylinder in, or nearly in, full gear, in which case the low-pressure cylinder had to take its chance of receiving its proper proportion of steam, or generally of not receiving enough. I should suggest that this unscientific method of working, though possibly the best in practice for this type of engine, came about through the want of synchronism due to the lack of coupling rods, such that the low-pressure piston could take up any position in its stroke relative to the high-pressure pistons. In fact, the whole arrangement has often reminded me of a German band, in which all the performers played in a different key. A writer in 'Engineering' some years ago pointed out this action, more particularly when the engines are starting from rest, and stated, what is often noticeable, that the high-pressure cylinders drove the train, and that the train drove the low-pressure cylinder.

I have made a good many observations on the running of these 3-cylinder engines, though nothing like so many as the author of the paper, but I have been more unfortunate than he, and have very little really good work to record as done by them, with the exception of one class, the "Teutonic," which seem to stand out head and shoulders above the others. The better results given by these 7 feet engines may be due to the larger wheels not getting out of step so soon with imperceptible slipping, as do the smaller 6 feet and 6 feet 6 inch wheels of the other types.

A fault of the 3-cylinder engines which might be mentioned is the immense reciprocating weight of a 30 inch low pressure piston, which at 60 miles per hour has to be brought to rest at the end of each stroke and restarted 538 times per minute in the case of the 6 feet 3 inch engines, and 480 times per minute in the case of the 7 feet class. In this respect the 4-cylinder compound with 20 or 21 inch pistons is much preferable, although the 3-cylinder engine has the advantage in having the large reciprocating mass in the centre line of the engine.

The author of the paper has referred to the two experimental 4-cylinder tandem compounds of the Great Western Railway built in 1886. I was present on the footplate at several trials of these engines; they failed, owing to mechanical defects. The first engine had the cylinders so constructed that the piston rod passed from the low pressure to the high pressure through a gun-metal bush which could not be lubricated, and the rods "seized" on several occasions. The other engine, which had three piston rods to each pair of cylinders, failed by constantly breaking the pistons. In some way it appeared that the 3-rod arrangement set up severe stresses owing to slight inequalities in the lengths of the rods, which may have been caused by unequal expansion. On one occasion this engine broke three pistons out of four when running, and I was not sorry when the trial terminated. But it was not the compound system that failed. Both these engines had the valve gear so arranged as to cut off in both the high pressure and the low pressure cylinders at the same point of the stroke. For the reasons I have mentioned with respect to the want of a suitable valve gear for simple engines, I consider that the 4-cylinder type is the coming engine for English main lines. I believe that Mr. Webb's engines of this class are doing excellent work, and the success of the de Glehn engines in France is absolutely assured. More than one English railway is already getting out designs for this type of engine.

The following communication was received from Mr. B. H. Thwaite subsequently to the reading and discussion of Mr. Rous-Marten's paper.

The modern locomotive even to-day has the two fundamental defects that were possessed by George Stephenson's "Rocket." It is inefficient as a thermodynamic machine; although the Americans have undoubtedly done something towards converting more heat into haulage energy. The mechanical principle of reciprocation as distinct from rotating

methods of dynamic energy, development, and transmission, is still common to all independent or self-contained locomotives. This reciprocating method of transmission not only sets up strains in the rolling stock, and makes absolute steadiness of haulage effect impossible, but the wear on the permanent way must be very severe and greater than are those of purely rotary methods of energy transmission. Although the Heilmann system has not, so far, attained commercial success, it, nevertheless, proved that by the adoption of a purely rotative method of transmitting the dynamic energy to the drivers, perfect running steadiness could be obtained.

There is little doubt but that the new century will see the displacement of the reciprocative steam locomotive engine by the electro-motor. The financial importance of a higher thermodynamic efficiency in modern locomotives has been realised, as one of the effects of the increased cost of fuel, and it is quite possible that the evils resulting from the abnormal price of coal may be more than compensated for by the lessons they have forcibly impressed upon us.

How are we to obtain a higher thermodynamic efficiency in modern British locomotives assumed to be compounded? Firstly, by means of better fuel combustion and heat transmission arrangements. Secondly, by superheating the steam. Thirdly, by reducing the loss of heat by cylinder side-wall radiation. To adequately demonstrate the first and second remedies would involve the preparation of two papers; but it may be suggested that the firebox of British locomotives might be advantageously enlarged, especially for the use of coal containing a notable percentage of hydrocarbons. The third remedy may be secured by the adoption of the writer's circulating mineral-oil or glycerine system; the glycerine being heated in a coil of copper pipes placed in the smoke box in such a way as not to interfere with tube-cleaning operations, the heated glycerine at a temperature of 350° Fahr. being forced by a simple rotary pump round a jacket enclosing the side walls and exposed ends of steam cylinders. By the adoption of the hot glycerine jacket the evils springing from the cooling currents of wind under the frame and set up by the rapid motion of the engine, and its tendency to produce condensation effects in the cylinders would be removed.

The British locomotives of the future must be designed to secure a more powerful haulage effect. What is wanted in England, is a test of all the more prominent locomotive designs under identical conditions of railroad and haulage and weight. This test could only be secured by one of the great railway companies permitting the use of their roadway for a particular

service, and in which the haulage pull on the tender-couplings could be made to be identical day by day, and for each test. The speed range of the power generators of the self-contained electric locomotive of the future, should be independent of that of the driver's crank-shaft, or crank-pin, so that in mounting gradients the speed of the power generator can be increased as desired to maintain an equal speed against the increased resistance due to the gradient. This characteristic of crank speed independence was possessed by the Heilmann locomotive, and is a most important and desirable advantage.

Mr. ROUS-MARTEN'S replies to the foregoing communications :—

In his communication, Mr. Ahrons observes that my expression, " the same volume of steam may be said, theoretically, to do a great deal more work in a compound engine than in a single one," is " somewhat apt to mislead," because " one pound weight of steam at a given pressure can only do a certain amount of work, whether that pound be expanded in one or in four cylinders." It is quite true, of course, that a given quantity of steam possesses only a finite power of work. But Mr. Ahrons forgets that the very point of the whole theory is that in non-compound engines a large proportion of that work-power is exhausted into the air, and thus is thrown away unused, whereas a compound engine uses most of that work-power which a non-compound wastes. It is not a case of getting more than twenty shillings worth of work out of 1*l*., but of getting, say, fifteen shillings worth with one engine, and only ten shillings worth with another. Of course these figures are purely arbitrary.

In the next place, Mr. Ahrons says: " All compound locomotives have drawbacks inherent to compounding; they cannot adapt themselves like the simple engine to both heavy and light loads," as the same locomotive " may have to work a very heavy down train and return with a light up train, and if it has been designed for the former work, it is generally a wasteful machine when put to the latter work." This surely is a *non sequitur.* I have found that a well designed compound can so graduate its output of power as to be by no means " wasteful," although of course it is at its best when working at its full power. But in any case the object is to get the heavy trains efficiently worked; the light ones may be left to take care of themselves.

Mr. Thwaite's remarks call for little comment on my part. With most of what he says I entirely agree, but I have had no experience in the working of his circulating mineral-oil or glycerine system, the adoption of which he advocates.

December 3rd, 1900.

CHARLES MASON, VICE-PRESIDENT, IN THE CHAIR.

RECENT PRACTICE IN SEWAGE DISPOSAL.*

BY HENRY C. H. SHENTON.

IN dealing with the subject of this paper it is necessary for the author, in order to make his meaning clear, to recapitulate many of the facts brought forward in the papers read before the Society of Engineers by Mr. Thudichum in 1896 and 1898. These two papers cover so much of the ground which must necessarily form the basis of any other paper on the subject, that reference to them is unavoidable. To those engineers who have made a special study of the subject of sewage disposal such references are unnecessary, but to those who have not made it a particular study some preliminary statement of facts is necessary.

It is essential, in order that the new methods of sewage disposal should go on to perfection, that the subject should be well discussed, the results of experience brought to light, and no hasty conclusions formed. Although innumerable papers and articles have been written on the modern treatment of sewage, the subject is one which will well bear discussion and upon which the last word has not as yet been said. In the following paper the author proposes to discuss practical details of construction and working, in the hope that the experience of the Members of the Society may be brought to bear upon them.

Before dealing directly with recent methods it may be well to state briefly, the ordinary ways by which up to the present time sewage has been treated.

1. It was often taken without any treatment direct into the nearest stream, river or lake, on the coast it was taken into the sea.

2. As an improvement on this system, sewage was treated with chemicals by means of which a great deal of the solid matter was deposited, generally in tanks, and the liquid, which was very little purified by this process, was run off as before, while a large quantity of sludge remained which had to be got

* The President's Gold Medal was awarded to the Author for this paper.

rid of somehow. Many attempts have been made to prove that this sludge had a marketable value, but it is indisputable that farmers do not want it and have frequently to be paid to take it away, and that it has never proved to be anything but a nuisance and the leading difficulty in sewage disposal works. In the words of Mr. Thudichum, "sludge is an abomination, and can be avoided."

3. Filters of various kinds have been used with results not very satisfactory. In the case of filters the sludge difficulty also remains.

4. The method of irrigating land with sewage has sometimes proved successful under advantageous circumstances, but it is not an ideal system, especially in the case of large towns where an extensive area is necessary for the disposal ground. For instance, to properly treat the sewage of London on land, 100 square miles of area would be needed, taking the population at 10,000,000 and the land at one acre for each 150 persons. The apparent failure of some irrigation works is, however, due to the fact that proper working conditions have not been maintained. More attention has been paid to the growing of crops on the land than to the proper disposal of the sewage. As a rule, irrigation works for town sewage disposal have been unsuccessful in the end.

All these systems are costly and need great attention to make them successful. They may, according to circumstances, be made to succeed, but it has been, until recently, a notorious fact that sewage disposal is always a matter liable to produce serious trouble under whatever system the works have been constructed.

One example may suffice. Sewage disposal works were constructed at Sutton in the years 1891–3. They included settling tanks and 18 acres of irrigation land. Sludge was precipitated by chemicals and the tank effluent irrigated the land. Part of the effluent was treated on artificial filters. Within two years these works, constructed with the greatest care, approved by the Local Government Board, and which also had not yet dealt with the full population they were intended for, failed. After this failure, the authorities, advised by Mr. Dibdin, constructed the first bacteria bed for the treatment of crude sewage ever made in the United Kingdom.

It is with the bacterial treatment of sewage that a paper on recent practice in sewage disposal must deal. This treatment consists of the resolution of impurity into inoffensive materials by the agency of micro-organisms. The process is present in all ordinary methods of sewage disposal, although not always under that name.

Scientists have pointed out that the ammonia smelt in a neglected urinal, the marsh gas which bubbles up from a stagnant pool, and the nitrate crystals which may be found on the whitewashed walls of old cellars and stables, are produced from organic matter by well-defined micro-organisms. Also that certain micro-organisms possess the power of oxidising ammonia to nitrate in the presence of air. It need scarcely be pointed out that while the organic matter from which these substances are procured by means of the micro-organisms is highly offensive, the ammonia, marsh gas and nitrate produced are inoffensive.

It has also been shown that micro-organisms are the agency which break up into useful forms all vegetable and animal matter on the earth's surface, and that changes formerly considered as purely chemical are due to the action of bacteria. By this process the land becomes charged with nitrates, which again nourish vegetables, and so on. Thus bacterial treatment for the purification of sewage is identical with the natural process by which the whole surface of the earth is purified.

Before proceeding to more practical engineering details, in order to explain the principles upon which new works are carried out, it is necessary to state that aerobic organisms are those which are active in the presence of air and effect the changes already described. Anaerobic organisms are active in the absence of air. They decompose cellulose and allied substances with the evolution of marsh gas. They remove oxygen from nitrates with the simultaneous oxidation of organic matter, and they decompose complex organic matter and produce ammonia, hydrogen, etc. Again, we are told that the liquefaction of solids may be brought about by aerobic organisms, but that it takes place more rapidly under the action of anaerobic organisms. Anaerobic action alone, though it may be good preliminary treatment, will only make sewage extremely foul and offensive. It produces putrefaction, which, however, is one step on the way to ultimate purification.

The bacteria necessary for the purification of sewage already exist in the sewage and, in the new systems, are carried with it either (1) to a tank where the liquid is confined out of contact with the air, where anaerobic organisms can work with great advantage; or (2) to beds filled with material of a kind which will provide a very large surface for aerobic micro-organisms to grow upon. In such beds aerobic organisms can work with great advantage, and the sewage is held in contact with them until sufficient time has elapsed for its purification, after which the liquid is run off, and the bed is allowed to stand empty for aeration.

Roughly speaking, there are two systems or principles upon which works for the bacterial purification of sewage are constructed:—

1. The septic tank system, in which anaerobic organisms are relied on to liquefy the organic solid matter in the sewage, and to prepare it for final oxidation in a tank, while aerobic organisms are relied on to produce the final oxidation or nitrification in bacteria beds.

2. What used to be called the Sutton system (which name seems now to be incorrect) in which aerobic organisms are relied upon to liquefy the solids, and also for the final oxidation of the effluent.

In other words, one method purifies the sewage by running it through a tank and then through contact beds, and the other method purifies it in contact beds without the use of any septic tank.

The name "Sutton system" appears to be incorrect, because it has been found at Sutton that a tank is practically of great use in liquefying solids, and the authorities are now passing all their sewage through a scum tank. It must be very satisfactory to the upholders of the septic tank process, that at Sutton, the place which gave its name to the alternative system, their own methods have, to some extent, been adopted. It is not well, however, to conclude too hastily that the tank system is the only practical one.

Although scientists have pointed out the useful work done by anaerobic organisms, they do not seem by any means to have proved that their work is essential to the final purification of sewage. They, however, differ considerably. Dr. Rideal, in an article published a few months ago, says, "Some recent experiments . . . . support me in the view which I have held for many years, viz. that an anaerobic preliminary is an essential for success." Mr. Thudichum, on the other hand, says, "Whilst fully alive to the powers of the anaerobic organisms, I do not, by any means, regard them as essential." Under the circumstances, it would be very rash for an engineer to express an opinion on the scientific aspect of the case, though he may well do so upon the practical work and results. To proceed, therefore, to practical matters, the bacteria bed, as first constructed by Mr. Dibdin at Sutton, and afterwards at many important experimental and final works, may be said to have been the outcome of the knowledge that the purification effected by filters under the old systems was chiefly due to bacterial action. Experiments at Massachusetts were probably the beginning of the reform in sewage treatment. After these experiments, Mr. Scott Moncrief, in 1892, produced his system for the

bacterial treatment of sewage, and later, many other experimental systems were brought forward, of which the most important, perhaps, was that of Mr. Cameron at Exeter, who brought forward his septic tank system in 1895. In 1895, also, the first contact bed for crude sewage was made at Sutton. Since then experiments too numerous to mention have been carried out with great success.

Under the old system, filters were generally used continuously for long periods, and soon became foul, owing to anaerobic action being much more powerful in them than aerobic action, there being no aeration to produce the activity of the latter. As soon as a filter was well aerated before use, and the liquid, instead of being allowed to run through, was held in the filter for a short time before being discharged, it became practically a bacteria bed.

There is a great difference, however, between a filter and a bacteria bed. The former strains the liquid, the latter has no straining action at all, but relies wholly on bacterial action. It receives the sewage till it is full to the surface, and holds it for a short time, during which time the aerobic organisms act upon the sewage. The sewage is then run off and the bed is allowed to stand empty, while the air necessary to support the activity of the aerobes can get into it. It can then again be used as before. As bacteria beds exert no straining action, it is surely incorrect and misleading to call them filters, or their effluent a filtrate, as is still the custom. They are frequently filled with coarse material such as 1½-inch clinker.

A bacteria bed, practically speaking then, is a water-tight tank, generally from 3 feet to 4 feet deep, filled with material providing a good surface for bacterial growth, such as clinker, broken stone or brick, burnt clay, ballast, etc. If sewage is turned on to such a tank bacteria will soon form colonies upon the filling material, and will exert their purifying action upon whatever sewage is brought into contact with them. It is usual to let the effluent from one such contact bed run on to a second contact bed, where it is treated as before. Generally speaking, the effluent from a second contact bed will be a clear, odourless and inoffensive liquid, even if crude sewage, without any tank treatment, has been run on to the first bed. Third contact beds are, however, not unusual, and are sometimes necessary.

Some time must elapse before the bacteria attain their greatest power in the beds. There is at first a rapid decrease in the capacity of the beds during the earlier period of working. Experiments have proved that the beds acquire practically a constant capacity in about three or four months. For instance, at the Manchester experiments, the capacity of one of the work-

ing beds was found to be identical when measurements of its capacity were taken one year apart. The first decrease in capacity is, no doubt, due, to a great extent, to bacterial growths which retain a portion of the liquid, and also, sometimes, to the disintegration and settling of the filling material.

It has been noticed that the time of resting has a marked effect upon the capacity of a bed. This is very probably due, in the case of a long rest, to the fact that micro-organisms are enabled to dispose of a certain amount of organic matter existing in the bed. In the case of a short rest it is due to the more complete drainage of the bed.

A septic tank is an air-tight chamber having inlet and outlet pipes at the same level, trapped. There are several methods of doing this, one of which is to let the inlet and outlet pipes dip below the surface as at Exeter (see Figs. 1 and 2). The tank is generally six or seven feet deep. Solid matter coming into such a tank will either sink to the bottom or rise to the surface, and while that is so, it is very clear that only liquid can be discharged at the outlet. In such a tank anaerobic organisms can act upon the organic solid matter and produce the changes already mentioned. Practically speaking, liquefaction of the solids is what takes place in the septic tank, and it is claimed by some that sludge will not accumulate in this tank and that it is not likely to need clearing out. The watchword of the Septic Tank Syndicate is "No Sludge."

In considering the merits of the two systems, it seems that a perfect system would be that in which the sewage was discharged direct from the sewers to bacteria beds, where the process of purification would be at once started, and where the increased putrefaction of a septic or other tank would not be present. A system in which a large mass of putrid sewage is stored as a step towards final purification, is surely not perfect. One may perhaps say that perfection is impossible, and it is not to be denied that, up to the present, the septic tank as shown in Figs. 1 and 2, or the open scum tank as shown in Fig. 3, seem to have proved themselves to be the best practical way of dealing with strong sewage in order to liquefy the solids.

At Sutton, the bacteria beds became clogged in course of time, and a scum tank was made to liquefy the solids, and, although works exist where no anaerobic tank treatment is used, it is not to be denied that the septic tank has proved itself to be a very practical method of avoiding the clogging of the first beds. Still, engineers would do well to bear in mind that much may yet remain to be done in working out a perfect system, and that, in spite of the excellent results obtained by

the septic tank process, it would be a better process if it did not include this mass of putrid sewage.

Again, while pointing out the admirable results obtained at Exeter and other works of the Septic Tank Syndicate, it is necessary also to point out an important instance in which anything but good results have attended the trial of an experimental septic tank, constructed by the Leicester Corporation. This tank was not put in by the Septic Tank Syndicate. A detailed report has recently been published referring to the Leicester experiments, in which the following results are given:—

Sewage, when allowed to pass through an open detritus tank, deposited 8·291 tons of sludge per million gallons. When passed through a closed detritus tank, the inlets and outlets of which were trapped, 5·40 tons of sludge were deposited per million gallons of sewage between November 11th, 1898, and February 25th, 1899. From March 1st to September 11th, 2·02 tons per million gallons. From September 19th to October 13th, 5·83 tons per million gallons. This sludge would naturally soon choke a tank, and is not at all what might have been expected, judging from results obtained elsewhere.

The report says: "This small quantity of sludge per million gallons deposited in the closed detritus tank, compared with that in the open detritus tank, is largely accounted for by the very long periods that it was used without emptying, when the sludge level in the tank reached a considerable height, and the whole of the contents were thick, including the supernatant liquid drawn off before measurement, a good deal of solid matter floated out in large lumps or flakes which, on opening the tank, were found to be belching up to the surface at very frequent intervals, the whole mass being in a violent state of fermentation. A good deal of solid matter escaped in these floating patches of sludge."

This is not at all a comforting description of a septic tank, and might well make one pause before deciding on the use of one. If a bacteria bed clogs, it can often be cleared by allowing it to rest for a few weeks. But if a septic tank fills with sludge easily, as at Leicester, the very greatest nuisance is experienced every time it has to be emptied.

The Leicester report further says: "It is also certain that frequent emptying is necessary to avoid nuisances, for I cannot speak too strongly of the awful stench I experienced when the covered detritus tank was emptied, after the 90 and the 151 days' periods of working."

Taking the Leicester closed detritus tank and the septic tank together, throughout the whole period the latter was in

use, the sludge deposited in the two amounted to 10·84 tons per million gallons; 7·04 tons per million gallons of this being in the septic tank. When an open settling tank was used with effluent from the open detritus tank, the yield of sludge was 14·86 tons per million gallons in 10 days. In 72 days it was 6·53 tons per million gallons.

The closed septic tank was used with the effluent from the closed detritus tank for 125 working days, without emptying, between June and October 1899. An average of 156,503 gallons per working day were treated. The total capacity of the tanks was 144,643 gallons. When opened, the septic tank had no complete thick scum on its surface, as is generally the case in such tanks. It is therefore not surprising that the stench from it was very offensive.

The Leicester report also says with reference to this septic tank: "The sludge when being discharged from this tank was so extremely offensive that the smell could not be escaped on any side, although there was a fair wind blowing at the time. 149 tons of sludge were found in this closed septic tank after 125 days' use." It will thus be seen that the capacity of the tanks, roughly speaking, was equal to one day's flow of sewage, and that sludge was deposited in the septic tank at the rate of over a ton a day, although the liquid first passed through a detritus chamber where heavy mineral matter, such as grit, would evidently be intercepted.

The author recently visited Leicester to make further inquiries as to the septic tank, and, through the courtesy of Mr. Mawbey, the Borough Surveyor, he ascertained that in the new works for the disposal of the Leicester sewage it is proposed to use a comparatively small open tank to intercept detritus, and not to have any large scum tank or septic tank at all. The author gathered that Mr. Mawbey considered a septic tank for Leicester would allow sludge to accumulate to a certain level, after which solid particles would be given off in flakes at the outlet, and that, although it might be of advantage to have such a tank, and although the sludge might not accumulate much when given off in this form, complete liquefaction would not take place. The effluent from the tank when run over pasture land on the broad irrigation system soon made the whole place in a stinking sludgy condition.

At Sutton, at the present time, the whole of the daily flow of sewage passes through a lightly covered scum tank, the capacity of which is equal to one-fifth of the daily flow. After close upon two years' work there are only a few inches of sludge in the bottom of this tank, although the scum is very thick. This tank has no grit chamber, or screen, and notwithstanding

the fact that it has only a light covering, through which air can pass freely, the smell, if any, is very slight. Of course, the crude sewage flowing through an open trough from the sewer to the tank, will cause some smell, but, to all appearances, the thick scum, which is sometimes 2 feet thick or more, effectually keeps any smell in. The effluent is free from solids, and does not clog the beds.

In the published results of the experimental septic tank installation at Belleisle, Exeter, we are told that the whole deposit in the septic tank, after 15 months' working, was only 80 cubic yards of sludge, whilst the original bulk of the suspended matters would represent over 600 cubic yards. Of this comparatively small deposit, doubtless a certain proportion still contained matter upon which the bacteria would act, and so must not represent the amount of matter which would remain permanently in the tank as sludge. The careful experiments at Manchester and many other instances might be quoted to prove the efficiency of the septic tank, but these do not, however, do away with the unsatisfactory results of careful experiments at Leicester.

It may be urged that the character of the sewage was particularly bad at Leicester, but this does not appear to be the case, and it must be remembered that it is for the treatment of exactly such sewage that the advocates of the septic tank recommend it. It therefore behoves all engineers, in remembering the practical advantages of the septic tank, not to make too sure that it is bound to be successful in dealing with every sort of sewage, and also to remember that, if it were possible to do without this tank and use only bacteria beds, the system would be the more perfect.

Most authorities seem to consider that a small grit chamber is a necessity before sewage enters the septic tank. Acting on the assumption that sludge will accumulate very slowly, if at all, in the septic tank, a grit chamber is made in which the velocity of the sewage is reduced to about 2 feet per hour, so that any road grit carried down the sewer is deposited, and the sewage passing to the tank contains therefore very little suspended mineral matter. If, however, road gullies discharge into a separate system, there appears to be very little advantage in a grit chamber. Also, if it is believed that the sludge in the septic tank will need removing frequently a grit chamber becomes unnecessary. The clearing of such a chamber will always, probably, cause a great nuisance. The Belleisle septic tank has its grit chamber formed inside the tank by building a wall about 7 feet from the inlet end right across the tank as shown in Figs. 1 and 2. The top of the wall is 1 foot below the surface of the liquid in the tank.

With regard to the size of septic tanks, the Local Government Board have required for various schemes submitted to them, that the tank should hold one-and-a-half times the dry weather flow of sewage in one day, with single contact bed treatment to follow. The safe minimum size for a septic tank does not seem to have been yet satisfactorily fixed. For instance, as has been already stated, the Sutton tank has a capacity equal to only one-fifth of the daily flow. The septic tank at Belleisle, Exeter, has a capacity equal to about 18 or 20 hours' flow of the sewage which passes through it, say one day's flow. At Barrhead, the capacity of the tanks is less than one day's measured flow of sewage and storm water. For the new works about to be carried out at Yeovil the tanks are to be equal to one-and-a-half times the expected dry weather flow, with double contact bed treatment to follow. It has been found at Manchester, by experiments conducted with two million gallons of sewage per day, that satisfactory results can be obtained if the septic tank capacity is one-half of the daily flow. The capacity of the tanks which gave such unsatisfactory results at Leicester was, practically speaking, equal to one day's average flow. Where the smallest tanks are used, sewage is of a foul nature, and difficult to deal with.

In view of the difficulties which may be experienced from sludge, it seems that it would be well, in designing new works, not to omit arrangements for emptying the sludge from the tanks, without disturbing the scum above. The floor of septic or scum tanks generally has a slight slope, and a well may be provided in connection with a sludge pump or drain, by means of which the sludge can be removed from the bottom of the tank without disturbing the scum. Mr. A. J. Martin, in a lecture delivered on December 13th, 1898, said that the Exeter tank had never required pumping out during the 28 months it had been working, and that the deposit on the floor at the end of that time was between 2 feet and 3 feet thick. The author believes that this deposit varies in thickness at different times, as other reports mention it as being only a few inches thick.

Regarding the depth of these tanks, the Exeter tank is 7 feet 9 inches at the deep end and 7 feet 3 inches at the shallow end. The Manchester experimental tank was 6 feet 11 inches at the deep end, and 6 feet 8 inches at the shallow end. The mean depth of the Sutton tank is 5 feet, and the depth of the Leicester detritus tank was 7 feet; the septic tank at the same place had a depth of 6 feet at the deep end and 4 feet 3 inches at the shallow end, which was also the outlet end.

It seems, therefore, reasonable to assume that from 6 to

7 feet is a suitable depth for a tank of this kind. It allows for a good depth of scum and of sludge and liquid. It is well to bear in mind that bad results may occur if the outlet from the tank is at too deep or too shallow a level. Obviously the inlet must be below scum-level so as not to break it, and the outlet should be below scum-level for the same reason, and also to ensure that liquid only passes out.

Mr. Martin, in describing the Exeter tank, says, referring to the outlet pipe, "If we had a single opening, the effluent would rush out in a strong current, which would be liable to drag down floating matter from the surface. To avoid this, a cast-iron pipe is carried across the whole width of the tank about 15 inches below the surface; and in the lower side of this pipe there is a continuous slot." The depth to which the inlets of the Exeter tank dip is 5 feet below the water-level.[1]

It is generally considered of importance, especially in open tanks, that the scum should not be disturbed. When the whole surface of the tank is covered with scum it no doubt assists the anaerobic action by keeping the sewage out of contact with the air. In an air-tight tank it may not be so necessary to keep this scum intact, but in an open tank it is essential. The reason that the scum is broken may account for some open tanks smelling so badly. If an open tank is used, it appears only reasonable to roof it lightly, say with corrugated iron, or by laying planks across the top. If this is not done, the wind alone will probably be sufficient to prevent the scum forming properly.

The inlet and outlet drains may be at the same level, and are generally so fixed. This is of great advantage at works where the fall is slight. It is also probably as well that the scum should remain at a constant level, and not be disturbed. There are, however, good reasons why this rule is not always strictly adhered to.

First, in the case of storm-water coming through the septic tank, it may not be convenient to allow it all to go into the bacteria beds used for the ordinary daily flow of dry weather sewage. The storm-water from sewers, after the first flush, is sometimes so clean as to need very little treatment. This is only the case with genuine storm-water, and not with the first flush of the sewers, which is likely to be exceptionally foul. It is then necessary to allow this first flush to enter the septic tank before the cleaner water is allowed to overflow on to any special area. An overflow weir is fixed in the inlet pit at such a level that no overflow can take place until all this foul flush has entered the tank.

Second, it is well to have the beds filled quickly, and not to allow a bed to take many hours filling, as would be the case if

the flow during the night were small, and were allowed to run through the tank to the beds. To ensure this regular flow, it may be necessary to allow the liquids to accumulate in a tank before it is discharged. Whether it would, or would not, be a good thing to have an automatic discharge from a septic tank, which should come into operation when sufficient liquid to fill one bed had entered the tank, is a matter which might perhaps be worthy of consideration and discussion.

Among the advantages of the septic tank are the facts, that the quality of the sewage is made fairly constant, which makes the treatment on beds an easier matter than where the sewage is very variable. Also, Dr. Pickard, at the Local Government Board inquiry at Exeter in November 1897, showed that from 70 per cent. to 90 per cent. of typhoid organisms, originally added to the sewage, were destroyed in passing through the septic tank, and that 88 per cent. of the remainder were killed in the bacteria beds; the survivors being so enfeebled that practically no chance of their becoming dangerous existed. This evidence should be compared with that to be found in Dr. Clowes and Dr. Houston's reports on the Barking and Crossness experiments, where it is distinctly stated that the treatment of sewage in coke beds does not remove bacteria to any appreciable extent.

It would appear from these statements that the septic tank performed the very important work of killing disease germs, and that bacteria beds did not. However, it is evidently once again impossible for an engineer to come to a conclusion of any value on the biological aspect of sewage purification, for Dr. Houston, in a paper recently published upon 'Modern Systems of Sewage Treatment,' confines his remarks to bacteria beds, because, he says, septic tanks, whatever their advantages may be from a chemical and practical point of view, cannot be regarded as much better than modified cesspools from the point of view of the epidemiologist. He also says that, in general terms, the mechanical separation of the micro-organisms in sewage by the use of bacteria beds is virtually impossible.

After this we must admit that we ought not to assume too readily that disease germs present in sewage are removed by any treatment in the septic tank or bacteria beds. It seems possible, from all one can gather, that the bacteria which are abundant in the effluent may cease to exist when they have no more matter for their support. The fact that a healthy man can drink the effluent from bacteria beds without harm proves nothing, although it is often quoted. Another advantage claimed for the septic tank is that its effluent, as a rule, needs treatment on one contact bed only.

Experience goes to prove that an open scum tank lightly roofed is just as effective as an air-tight tank. At the Manchester experiments, for instance, the results from open and closed tanks were identical. The advantage of the open tank over a closed one is that the expensive concrete or brick roof is avoided. In open situations away from houses an open tank lightly roofed would probably do well; if near houses an air-tight tank would probably be best, as there may be considerable smell before the scum is formed or in case the scum is disturbed. It is a fact, that if the scum is transferred from a tank which has to be cleared to one which has to be started, the septic action in the new tank may be started in a few days.

Messrs. Cameron, Commin and Martin have succeeded in utilising the gas generated in their septic tank at Exeter for lighting their works by using it with an incandescent mantle. Also recently they have succeeded in using it for other purposes. At the present time an 8 horse-power steam engine is being run at Exeter, the steam for which is generated in a boiler heated with gas from the septic tank.

It can easily be seen, without any special knowledge or experience, that bacteria beds cannot possibly deal with road grit or other mineral matter if it is present in sewage. It is folly to allow such material to clog the beds. It therefore seems essential that some arrangement for catching grit should come before the bacteria beds. Bacteria beds may give good results at one place which at another would fail owing to the different quality of the sewage. Experience points to the fact that, with a small detritus tank or grit-chamber, bacteria beds will deal with crude sewage without becoming clogged. If they become clogged with organic matter they can easily be cleared by allowing them to rest for a few weeks. The whole of the work of purification can be done on the bacteria beds.

The grit having been intercepted, it is an open question whether screening is not a mistake. Practically it may be found impossible to do without screening, but this may be due to the imperfections of the bacteria beds. A screen is obviously unnecessary where a septic tank is used, and it may be of interest to know that the much-talked-of revolving screen at Sutton has been given up and that all sewage passes unscreened into the scum tank. Screens collect sludge which ought to be otherwise dealt with, and which is sure to smell badly. They seem therefore not to belong to the perfect system which should be aimed at. To avoid smell, the large open channels, so often seen, which convey crude sewage to the beds, might, with advantage, be omitted from new works. Sewers would answer the purpose

just as well and would smell less. If one took away the smell at the sewer outfall and that at open tanks and channels, there would, as a rule, be practically no offensive smell at works where bacteria beds are used. A little smell where the sewage discharges on to the first bed may be unavoidable, but with this small exception there need be no smell at properly constructed works. In the author's experience bacteria beds do not smell of themselves even when badly clogged. This fact is borne out by various experiments of which reports have been published.

With regard to the size of the beds and their most effective depth, it is necessary to remember that the objection to large beds is that they will take too long a time to fill and empty. The Manchester experts recommend that the beds for that city should be about half an acre each in size and 3·33 feet deep. At Hampton each bed is about 34 feet by 50 feet and 4 feet deep. It is essential that each bed should be capable of being rapidly filled and emptied, and as previously stated, that it should not be of such a size that it would take all night to fill when the flow is small. Also, it is easier to allow a bed to rest when there are several small ones than when there are one or two large beds.

With regard to the depths of beds, the Local Government Board seem to be of the opinion that 4 feet is the maximum effective depth. The Leicester report recommends a depth of 4 feet 4 inches, and the Manchester report 3·33 feet. The author is not, however, aware that any very definite reasons have been given for taking 4 feet as the maximum effective depth.

The reports published upon the Crossness experiments say that coke beds similar in character but differing in depth, have been found to give practically identical results. A bed 13 feet deep has been tried. Further information on this important point would be of great interest, although the fact remains that practical experience may point to the fact that from 3 to 4 feet has been found to be the best depth for bacteria beds at most works.

With regard to the filling for beds, it is, in the author's opinion, very necessary that good material should be used, and he thinks that it will be found well worth the extra cost. It seems very probable that bad results are often due to the disintegration of the filling material. At Manchester, the drains of one of the experimental beds became choked with fine cinder. Those who have examined coke beds will know that fine particles of coke will be found adhering to each large piece of coke in the bed, evidently due to the disintegration of the material, and that this deposit is largely instrumental in re-

ducing the capacity of each bed. In the case of burnt ballast, the disintegration that takes place is considerable, as is very well known to all who have had to deal with it. Extra burning will however produce greater durability. The advantage in cost of this material in clay districts accounts for its use at so many works, where its surface is generally protected by a layer of clinker.

At Leeds it was found that in about two months one of the coke beds was sludging up, and though the result was considered chiefly due to the matter in suspension not being digested fast enough, it was also considered partly due to the filling and settling of the coke. All authorities seem to agree that hard furnace clinker as a filling for beds gives the best results, and as, after all, the cost of the material for beds is not one of the heaviest items in the construction of works, it seems very well worth while to obtain the best material.

Some difference of opinion appears to exist as to the size of the material to be used for the coarse first contact beds. The Manchester experts recommend, for new beds, clinker of a size to pass a 1½-inch mesh and to be retained by a ⅛-inch mesh. At Leicester the material recommended for coarse beds is that held on a ¾-inch mesh and passing through a 3-inch mesh. At Hampton the coarse beds are filled with material held on a ½-inch mesh, and at Sutton with ⅜-inch material, as stated in a published report. The author recently carefully inspected a section cut in a Hampton first contact bed, where the bulk of the material appeared to be at least 1 inch in size or larger. In passing, it is worthy of notice that, although the surface of this bed was badly clogged, the inside was quite clear.

The table given on the next page is taken from the Sutton report, and shows the results of some experiments as to the relative value of various materials for filling beds.

In regarding bacteria beds which have to deal with crude sewage one is frequently struck by the fact that the first beds are more or less dirty or choked, while the second beds are quite clean. The idea at once presents itself that the first beds are doing much more than their share of work. Let it be granted that this is so, and we are confronted with the fact that either the first bed does too much work or that the second bed does too little. However much the first bed may clog, its effluent will generally be found to be of the same quality. The second bed will be found as a rule not to clog, even though the first bed is badly sludged up. Experiments have sometimes proved that when a single contact has been insufficient to purify the effluent, double contact has been more than sufficient. It is then surely well worthy of consideration whether

SUTTON (SURREY) URBAN DISTRICT COUNCIL.

FINE GRAIN BACTERIA FILTERS.

TABLE OF CAPACITY AND OTHER DETAILS OF FILTERS.

No. of Filter.	Materials.	Area.	Depth.	Total Capacity of Filter.*	Average Quantity of Effluent treated at each Charge.	Percentage of Effluent at each Charge to total Capacity of Filter.	Average Quantity of Effluent treated per cubic yard of filtering material per day, charging three times.
		sup. yds.	ft. in.	cubic feet	gallons		gallons
1	24 inches burnt ballast 5 ,, pea gravel 5 ,, coarse gravel	$77\frac{7}{9}$	2 10	1,983	3,494	28	142·8
2	3 inches pea gravel $10\frac{1}{2}$,, polarite and sand 4 ,, extra coarse 3 ,, pea gravel 5 ,, coarse shingle	$77\frac{7}{9}$	2 $1\frac{1}{2}$	1,487	2,403	26	131·1
3	8 inches $\frac{5}{16}$ coke breeze $12\frac{1}{2}$,, over $\frac{5}{16}$,, 5 ,, extra coarse sand 4 ,, pea gravel 5 ,, coarse gravel	$77\frac{7}{9}$	2 $10\frac{1}{2}$	2,012	4,369	35	175·9
4	8 inches $\frac{5}{16}$ coke breeze 13 ,, over $\frac{5}{16}$,, 5 ,, extra coarse sand 4 ,, pea gravel 5 ,, coarse gravel	$77\frac{7}{9}$	2 11	2,042	4,587	36	182·0
5	20 inches sand 5 ,, coarse sand 5 ,, pea gravel 5 ,, coarse shingle	$77\frac{7}{9}$	2 11	2,042	3,712	29	147·3
6	$19\frac{1}{2}$ inches sand 5 ,, coarse sand 5 ,, pea gravel 5 ,, coarse shingle	$77\frac{7}{9}$	2 $10\frac{1}{2}$	2,012	3,819	30	153·8
7	10 inches coke breeze passed through $\frac{3}{8}$ mesh 22 inches burnt ballast rejected by $\frac{3}{8}$ mesh	$465\frac{7}{9}$	2 8	11,179	22,278	32	161·4
8	4 inches coke breeze 29 ,, burnt ballast	$684\frac{4}{9}$	2 9	16,940	33,200	32	158·7
	Totals and averages			39,697	77,862	31·38	158·8

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April 1899.

some of the work cannot be taken off the first beds and given to the second.

The Manchester experts in their report say: "Single contact cannot be safely relied on to effect purification, whilst double contact is generally more than sufficient"; and also that by mixing the effluent from a first contact bed with that from a second contact bed a liquid was obtained which withstood severe tests and was incapable of putrefaction. They also state that according to their experiments the second beds need only be one-fifth of the area of the first beds.

Thus, part of the effluent from a first bed can be taken direct to the effluent from a second bed, and the latter will purify the former. Four-fifths of the work under the circumstances referred to may be said to have been done by the first bed, and one-fifth by the second bed. If the beds are of equal capacity, as is generally the case, one can hardly be surprised if the first contact bed gets clogged. If, however, as recommended in the Manchester report, we reduce the area of the second contact bed to one-fifth the size of the first contact bed the same thing happens, and the first bed is still overworked; the second bed is charged with purified liquid once while the coarse bed is charged with very foul liquid once. Is it not worthy of consideration therefore that an attempt should be made to let the foul sewage run on to the coarse bed and through it, with some of its sludge if necessary, to the fine bed?

Possibly a very coarse bed of durable material, very well drained, would produce the result of a more or less sludgy effluent from the first bed of a quality very inferior to that usually obtained, yet good enough to be absolutely purified by the second contact bed, or if necessary by a third bed. The object is that the first beds should not sludge up, and that the second and possibly third beds should do their proper share of the work. The author would, therefore, beg those interested in the subject to give this matter careful consideration. What is needed to perfect the bacteria bed system is some way of preventing the sludging up of the first beds. The second beds, so far as the author's experience goes, do not give trouble at the worst places. Were it not for the sludging up of the first beds the tank treatment would be unnecessary.

The drainage of beds is an important point. They are under-drained so that the liquid may be quickly collected and run off. Open jointed pipes are frequently used, but, in the author's opinion, sunk channels with perforated covers are better for several reasons. In the first place, it is well to have the outgo from the bed level with the floor in order to discharge

the full contents of the bed; at the same time it is well not to leave the drains empty when the bed is emptied, because they will then stand full of unfiltered sewage when the beds are next filled, which will cause the first rush of effluent to be foul. If, however, the outlet is above the drains, upon emptying the bed the drains will retain the last of the effluent and the preliminary rush of bad effluent will be avoided. Figs. 4 and 6 show the arrangement described. A wash-out is provided by which the drains can be emptied, if necessary.

It will be seen that, if the drains were not below the bottom of the bed as shown in Fig. 5, the last three or four inches at the bottom of the bed would be wasted. Next, it has been found that a fine black sludge accumulates between the drains, which may be the means of blocking them up on the underside, and which has little chance of being carried off by such drains. Channel drains with perforated tops would be able to take it away. This black sludge has been often described. It has been compared to the ash which remains after the combustion of materials by fire, and has been called the ash of sewage. It occurs at the bottom of a septic tank, or of a contact bed. It has no objectionable smell, and generally contains a large number of small worms. More information as to its character, and the quantity likely to accumulate from a certain quantity of sewage treated, would be of interest. Neither septic tank nor bacteria bed appear to deal with this substance. The author has observed a large deposit of it in an effluent trench. The effluent was from sewage treated in a covered septic tank and two contact beds.

Many very competent authorities strongly advise that the size of the material upon the surface of the first contact bed should be fine, to prevent sludge getting into the interior of the bed. On the other hand, those who have visited works of the kind lately may probably have been struck by the fact that the top layer of the first bed is generally of the very coarsest material. If it is granted that a bacteria bed will deal with sludge, it seems false to exclude it or keep it on the surface of the bed. The object of bringing sewage to a bacteria bed is that it may be distributed over an enormously extended surface in contact with bacteria. This does not happen to sludge if it remains on the surface in a layer some inches thick. If, on the other hand, a bacteria bed will not deal with sludge, why bring it there at all? In any case, it does not appear reasonable to leave it all on the surface of the first bed, where it must prevent aeration to a great extent. That a great deal of sludge will remain on the surface, however coarse the material may be, is very likely, but it can be more easily removed from among

the very coarse material than from among the very fine with which it will form one mass.

As a compromise, the method has been tried of covering a small area of the bed, say 12 feet square, near the sewage inlet, with very fine material sprinkled for a depth of, say, $\frac{1}{2}$ inch over the surface of the ordinary bed filling. Upon this area, and over the area of the whole bed, a 6-inch layer of unbroken clinker is then laid. A ridge of clinker is also formed around the edge of the 12-foot area. It will be readily seen that no large solid matter can get over the clinker-ridge through which it will be more or less strained or broken up. Also the large solid matter retained on the 12-foot area will not get into the interior of the bed until it has been dissolved and washed through the half inch of fine stuff below. The rest of the surface of the bed will not get clogged, so that plenty of aeration can take place, and when the 12-foot area becomes clogged it will only be for a depth of 6 inches, and this can easily be cleaned and the sludge removed. This method has been found to give good results, and takes the place of a screen. So much of the work is, as a rule, done by the first contact beds that the second contact beds may be made of very fine material, say $\frac{3}{16}$ inch or even finer, and yet show no signs of clogging up. Also, the third beds, where they exist, are generally made of yet finer material.

Whatever differences of opinion exist, it is generally agreed that the first beds must not be of too fine a material, or they are sure to clog up. The author has found, at experimental beds at Ash in Kent, that two beds of identical size, made in the spring of 1899, and filled with broken coke, though working side by side under exactly the same conditions, gave very different results. One bed, about five months after use, became so clogged as to be of very little use. The other, however, has worked well up to the present time, its liquid capacity being about one-third of the whole bed before coke was put in. The capacity of the clogged bed is about a quarter that of the other, and its effluent appears equal in character to that of the best contact bed.

The sewage treated in these beds is screened crude sewage consisting chiefly of brewery refuse. The size of the coke in the clogged bed is very slightly smaller than that in the other, the sizes being, roughly speaking, 1 inch and smaller in the good bed, and $\frac{3}{4}$ inch and smaller in the clogged bed. This slight difference in the size of the material seems to have produced the remarkable result of making one bed a success and the other a failure. Trial holes were recently sunk in each bed; neither bed was at all foul, a strong earthy smell only being detected in each.

It is customary to distribute the liquid over the beds in open channels. It does not appear, however, in the case of first beds, that such channels are very necessary unless, as in the case of the experimental beds mentioned in the Barking and Crossness reports, these channels are converted into settling troughs, in which the gritty matter may be deposited. This idea seems an excellent one. Troughs for first contact beds have been frequently abandoned and replaced by platforms to prevent the rush of sewage disturbing the bed. It appears that channels in the second bed are useful to catch any gritty matter washed out of the first bed, and also to intercept the black sludge already referred to as sewage ash, which may come through the first bed. Such channels should overflow on to the second bed, and are not so much distributing as settling channels. Any grit or sludge intercepted can be easily removed, and, in all probability, will be quite inoffensive. As a rule, the third contact beds have no distributing channels.

Failures of bacteria beds seem to be due either to overworking them and to allowing grit to clog them, or to insufficient drainage and too small a filling material. Taking the bacteria bed at its worst, if it is overworked, it will sludge up, but unless this sludging is due to mineral matter, a few weeks' rest will restore it to its normal state. Thus, if only a sufficient number of beds were made, the worst sewage could be dealt with by bacteria beds alone. If, by negligence, a bed gets clogged with grit, the very worst that can happen is that the old material will have to be taken out of the bed and the bed re-filled with new material. This, of course, may be considered a serious expense, but it is not likely to happen often, and probably the old filling material could be washed and reserved for future use. However, at the worst, such a failure cannot be compared to a polluted river or large irrigation area, which, if it fails, advertises the fact far and wide, and cannot easily be cured.

It is false to assume that beds are a failure because they clog up when filled with exceptional sewage. It is generally very clear that beds which give bad results under such circumstances are being overworked, and they would no doubt prove satisfactory if used, perhaps, twice or even only once a day instead of say three times. It is well, for experimental purposes, that beds should be worked to their uttermost, but to do the same thing for ordinary working is necessarily wrong and false economy.

If a first contact bed should clog up, say in two years, it is apt to be regarded as a failure, whereas the cost of removing the old material and cleaning it, or of re-filling the bed with new material, would, after all, probably be less than that of the

disposal of one year's sludge under the old system. If contact beds fail, it is probably because their capacity is insufficient to deal with the flow of sewage.

A town with a population of 33,000, having a flow of sewage equal to a million gallons a day, would need about 220 acres for land treatment, taking 150 people to the acre. First and second contact beds, to do the same work, 4 feet deep, and filled only once a day, would cover an area of a little under two acres, and if filled three times a day, would cover an area of about two-thirds of an acre. It is not too much to say, that beds which were filled three times a day for one week, and then allowed to rest for two weeks, would deal with any organic sludge.

It has been satisfactorily proved at Manchester, Yeovil and elsewhere, that bacteria beds will deal with any ordinary manufacturing refuse diluted with sewage. Yet, in the author's experience, great difficulty has been found in dealing with brewery refuse. In this matter engineers may save themselves great trouble if they can get the brewers to filter their waste. Hops in large quantities are particularly difficult to deal with, and may be easily intercepted at the breweries. At Guildford, at the present time, the brewers are going to filter their refuse before taking it into the sewers.

The Septic Tank Syndicate arrange that their system shall work entirely automatically, and the advantages of automatic working cannot be too highly appreciated. An illustration of their alternating gear for filling the beds is shown in Fig. 7. The following is Mr. Martin's description of the gear:—"The filters in the working set are grouped together in pairs, and the supply and discharge valves for each pair are suspended from the opposite ends of two levers, which are connected to one shaft. The same shaft also carries a couple of copper actuating buckets, which furnish the motive power. As soon as a filter is full, a small quantity of filtered effluent overflows from its discharge well into one of the actuating buckets belonging to the other pair of filters. As shown in the engraving, filter No. 2 is full, and has so remained while filter No. 4 was filling. The latter is now full, and is overflowing along this pipe into the actuating bucket, which is seen in the higher position. When this bucket is full, the weight of the water in it will overcome the pressure of water on the discharge valve of filter No. 2, and the bucket will descend. The shaft will turn in its bearings, thereby rocking the levers which carry the valves. The discharge valve of filter No. 2 will be opened, so that the filtered effluent will be released and pass out into the river. At the same time the valve through which this filter was opened will be closed, and another valve opened to fill filter No. 1, the

discharge valve of which will then be closed. The same motion will bring up the opposite actuating bucket to receive the overflow of filter No. 3 when this filter is in turn filled. This action goes on in endless succession, so that each filter is in turn filled, rested full, discharged and aerated, in the order stated."

Of other automatic apparatus, that patented by the Adams Sewage Lift Company, and shown in general plan at Fig. 3, and in detail at Figs. 8 and 9, is worthy of notice. The discharge of sewage into bacteria beds is effected through syphons, in each of which the sewage is held back by an air-lock when it is not discharging. As liquid rises in a bed to its proper level, it is made to produce this air-lock in the inlet syphon, and so as to stop its flow. It is also made to produce the removal of the air-lock in one of the other syphons, which forthwith begins to discharge. The automatic inlet syphon is shown in Fig. 8. As the liquid rises in the bed, it is admitted through a small regulating valve to a pit in which the syphon is placed. By this valve the bed can be made to stand full for any required time before discharging. When the liquid has risen to the required height in the syphon-chamber, the syphon is discharged through the outlet valve shown at Fig. 9, so that the bed is emptied quite automatically. This automatic inlet and outlet apparatus will fill beds, allow them to stand full, empty and allow them to stand empty alternately in endless succession.

This apparatus is free from moving parts, and is applicable, in various modifications, to the contact beds or continuous flow filters, regardless of the system of tanks, etc., employed. The supply apparatus is in effect a plain D-trap, as shown at Fig. 8, through which liquid passes from the sewage carrier or channel to the bed. A dome attached to an air-pipe, connected to the summit of the feed syphon, is suspended within the bed, at such a level that when the latter is full this is immersed in the rising liquid; the air from within the dome is displaced by this liquid and forced back under pressure through the air-pipe to the feed syphon, in which it creates an air-lock, which prevents the further passage of liquid through the apparatus, the liquid remaining shut off until this air is liberated. In the meantime the air displaced from another smaller dome in the same bed has been transferred to the feed syphon of the adjoining bed, where the excess pressure bursts the liquid seal and allows the free passage of sewage to the bed. In this way the supply is shut off by the rising liquid in a bed, the same rising liquid bringing on the supply to the next or any bed desired, the whole being so connected by a series of air-pipes, that any one bed may be cut out of work for recuperation or other purpose.

The filling of the beds is thus provided for, their discharge

is brought about in a very simple manner. For this purpose a syphon of special construction, shown in Fig. 9, is used; it is combined either with an attached overdraw pipe or a distinct pipe serving the same purpose. The syphon is placed in a small chamber similar in every respect to a flushing chamber; the overdraw pipe reaches over the chamber wall, dipping into the liquid contents of the bed which it is destined to empty. The supply of liquid to the flushing tank is drawn from the bacteria bed, a tap controlling its flow. This tap is set, where two hours' contact is desired, to fill the flushing chamber in two hours; if three hours' contact is required, in three hours; and so on. When the chamber fills the syphon comes into action, discharging simultaneously the contents of its own chamber and of the bed. This apparatus is in operation at the Sutton, Hampton, Guildford, Epsom, Ealing, and other works around London.

The feed apparatus may be also used in case of storm to close the passage to the channel supplying the beds in order that the liquid may pass direct to the storm-water filters. For private installations ordinarily one feed is sufficient, the adjoining bed being supplied with a weir only. The first bed becoming full and its feed locked, the liquid in the supply channel rises to the level of the weir, over which it passes to the second bed. This fills, and in turn, through its air-dome, liberates the first; both discharge by timed syphons. Some such apparatus as the foregoing may be regarded, practically speaking, as essential at sewage disposal works to ensure the regular working of the beds.

With regard to beds for the treatment of storm water, it has been found that being only occasionally used leaves them in an excellent condition. Analyses show that a prolonged period of rest tends to promote the storage of nitrate in a bed, and consequently to increase its purifying power.

In the proposed new works for Yeovil, the Septic Tank Syndicate have ingeniously arranged that while in dry weather all sewage, after tank treatment, goes on to first and second contact beds, in wet weather, when the effluent exceeds the amount with which the first beds can deal, the excess runs to the lower filters, and the amount of filtered effluent running to the lower filters will then be reduced. In very wet weather, when the maximum flow is being received, the lower filters will deal solely with unfiltered dilute tank effluent, or, in other words, this dilute effluent will receive single contact treatment only. This is managed by taking the effluent from the first beds into an aerating pond, from which it will either pass to the second beds or escape over an overflow weir to the irrigation area.

SEWAGE DISPOSAL SCHEMES.—LOCAL GOVERNMENT BOARD REQUIREMENTS.

TABULATED BY MR. S. H. ADAMS.

Under any system it is necessary to provide means for treating a volume of sewage equal to SIX times the dry weather flow. Of this volume a quantity equal to THREE times the dry weather flow must be treated as sewage proper. The excess from three times up to six times the dry weather flow may be treated upon special storm-water filters, or on specially prepared land.

The table below shows these requirements applied to various systems.

System.	Capacities.				Area.
	Sedimentation Tank, taking Screened or Unscreened Sewage.	First Contact Beds, taking Tank Effluent.	Second Contact Beds, taking Effluent from First Beds.	Special Storm Water Filters.	Land for Final Treatment of First Three Volumes.
No. 1.—SEDIMENTATION TANK, WITH DOUBLE CONTACT.	One day's dry weather flow.	3 times dry weather flow, 2 fillings per day of 16 hours, on 8 hours cycle, proportion of medium to liquid = 3 to 1, with storage for night flow.	Same as for first contact beds.	Three times dry weather flow at 500 galls. per yard super.	One acre per 1000 persons.
Example for 1000 persons at 30 galls. per head per day of 16 hours, dry weather flow (night flow to be stored), at 2 fillings per day.	$1000 \times 30 \times 1$ = 30,000 galls. = 4800 cub. ft.	Total cubic capacity $= \dfrac{1000 \times 30 \times 3 \times 3}{2 \text{ fillings}} \div 6{\cdot}25$ = 21,600 cubic feet = 8 beds, each 2700 cubic feet, with storage for night flow.	Same as first contact beds.	$\dfrac{1000 \times 30 \times 3}{500}$ = 180 yards super.	One acre.
If beds are worked automatically 3 fillings are allowed per day of 24 hours on 8 hours cycle (no storage required for night flow).	As above	Total cubic capacity $= \dfrac{1000 \times 30 \times 3 \times 3}{3 \text{ fillings}} \div 6{\cdot}25$ = 14,400 cubic feet = 8 beds, each 1800 cubic feet, for night flow.	Same as first contact beds.	180 yards super.	One acre.
No. 2.—SEDIMENTATION TANK, WITH SINGLE CONTACT.	$1\frac{1}{2}$ day's dry weather flow.	As No. 1	Nil	Three times dry weather flow at 500 galls. per yard super.	One acre per 1000 persons.

For examples on this system see those above, omitting the second contact beds, and providing sedimentation tank for $1\frac{1}{2}$ day's flow = $1000 \times 30 \times 1\frac{1}{2}$ = 4500 galls. = 7200 cubic feet.

No. 3.—Double Contact, without Sedimentation Tank.	Nil, but screening necessary and sedimentation tank to some extent desirable.	Same as No. 1, but proportion of medium to liquid = 4 to 1.	Same as for first contact beds.	Three times dry weather flow at 500 galls. per yard super.	One acre per 1000 persons.
Example for 1000 persons at 30 galls. per head per day of 16 hours' dry weather flow (with storage for night flow), 2 fillings per day.	Nil, but screen chamber required.	Total cubic capacity $= \frac{1000 \times 30 \times 3 \times 4}{2 \text{ fillings}} \div 6{\cdot}25$ = 28,800 cubic feet = 8 beds, each 3600 cubic feet.	Same as first contact beds.	180 yards super.	One acre.
If beds are worked automatically 3 fillings are allowed per day of 24 hours on 8 hours cycle (no storage being required).	Do. do.	Total cubic capacity $= \frac{1000 \times 30 \times 3 \times 4}{3 \text{ fillings}} \div 6{\cdot}25$ = 19,200 cubic feet = 8 beds, each 2400 cubic feet.	Same as first contact beds.	180 yards super.	One acre.
No. 4.—By Continuous Filtration with Sedimentation Tank or Precipitation.	$1\frac{1}{2}$ day's dry weather flow.	3 times the dry weather flow, filter not less than 6 feet deep, and at rate of 200 to 400 galls. per yard super.	Nil	180 yards super.	One acre.
No. 5.—By Continuous Filtration without Sedimentation Tank.	Screening required.	As No. 4, but 1 yard super required as minimum for every 200 galls. of sewage.	Nil	180 yards super.	One acre.

No. 6.—If Sewage is treated by Broad Irrigation on *suitable* land, after rough screening, the requirements are one acre of land for every 150 head of population.

Notes.

The maximum efficient depth for first and second contact beds is about 4 feet.

If beds are not worked automatically, only 2 fillings per day of 16 hours are allowed, and provision must be made for storing the night flow.

If beds are worked automatically, 3 fillings per day of 24 hours are allowed, and no storage for night flow will be required.

The effluent from the special storm-water filters may pass direct to the outfall.

The effluent from sewage must be finally treated upon land.

If desired, a specially reserved and prepared area of land may be substituted for the storm-water filters; the actual area required depends entirely upon the quality of the land.

Storm-water overflows must come into action only after the volume is in excess of SIX times the dry weather flow.

In cases where the sewers are laid on the separate system, the above requirements as to storm-water filters and land may possibly be reduced, but each case is considered on its own merits, and no rule can be formulated.

The 8 hours cycle of operation is as follows:—1 hour to fill, 2 hours resting full, 1 hour to empty, and 4 hours resting empty for aeration.

It is desirable to provide one bed in excess of the actual requirements, so that each bed in rotation may be left out of work for one complete week for recuperation.

1000 cubic feet filter capacity, inclusive of medium at 3 fillings per day, will deal with 1000 cubic feet of settled sewage, or 750 cubic feet of unsettled sewage.

Sedimentation tanks are generally 5 feet to 6 feet deep.

The number of beds employed is optional.

Before leaving the subject, it is well to point out that the system which will deal with the Manchester sewage, and which we hope to see at no very distant date purifying the whole of the sewage of London and restoring the Thames to its position as a salmon river, is equally good for dealing with the sewage of the smallest village, or for that of a barrack, as seen at Fig. 10, or a private residence, as shown in Fig. 11, or even a cottage. It is a cheap system, and it is under perfect control.

In conclusion, the author wishes to express his thanks to Messrs. Cameron, Commin and Martin for the valuable information they have afforded him, and also to the borough surveyors and others who have kindly allowed him free access to their works or have assisted him with information. He also wishes to express his thanks to Mr. S. H. Adams, who has kindly assisted him with diagrams for his paper, and has also allowed him to publish the accompanying Local Government Board Regulations which Mr. Adams, in dealing with many new Local Government Board schemes, has been able to compile. It should be observed that there are none at present officially published.

DISCUSSION.

The Chairman said that it was his pleasing duty to propose a vote of thanks to Mr. Shenton for his admirable paper.

The vote of thanks was accorded by acclamation.

The Chairman said that a professional report of Mr. Mawbey's had been referred to in the paper, respecting which Mr. Mawbey desired to make an explanation before the discussion commenced. He was sure the meeting would have much pleasure in hearing Mr. Mawbey.

Mr. E. G. Mawbey said that he was not going to make any serious objection to what had been read, because he thought that the paper was too admirable to merit any censure, but a little difficulty had arisen. After describing the quantities of sludge that were produced by the detritus tank, the author said: "This is not at all a comforting description of a septic tank, and might well make one pause before deciding on the use of one." Mr. Shenton had mistaken the detritus tank for the septic tank. The floating out of large flakes which was mentioned in the passage quoted from his (Mr. Mawbey's) report took place from the detritus tank and not from the septic tank. The detritus tank was a small tank, whereas the septic tank was 130 feet by 30 feet; so it was clear there had been a misunderstanding. The solid matter never flaked out in large lumps from the

septic tank. A little later on there was a mention of 14·86 tons of sludge per million gallons when the detritus tank was used for 10 days, and 6·53 tons per million gallons in 72 days. But it should also be pointed out that that sludge contained 97 per cent. of water. That was from the open settling tank (which was 130 feet long) before it was covered over and converted into a septic tank.

Lower down on the same page there seemed to be a misunderstanding. The author stated: "It is proposed to use a comparatively small open tank to intercept detritus, and not to have any large scum tank or septic tank at all." They were going to have rather large detritus tanks. The paragraph continued, "The author gathered that Mr. Mawbey considered a septic tank for Leicester would allow sludge to accumulate to a certain level, after which solid particles would be given off in flakes at the outlet." There was a little confusion here. What was spoken of happened with the detritus tank and not with the septic tank. What he intended to convey to Mr. Shenton in the information he gave him was that, although that was what happened to a detritus tank, after the septic tank had been in use for a long time, and the sludge had accumulated to a certain level, or to a certain extent, the solid matter would float out in finely divided particles but not in flakes. That was really what happened at Leicester.

As to the crude sewage at Leicester, it would probably be well to mention that the average of the albuminoid ammonia was 1·2, and the oxygen absorbed 7·5 grains per gallon.

The only other point requiring explanation was later on in the paper, and had reference to the coarse material which, instead of being 3 inches, was $1\frac{3}{4}$ inch. In two of the first contact beds the sizes were from $\frac{3}{4}$ inch to $1\frac{1}{4}$ inch, and in the other two beds the sizes were from $1\frac{1}{2}$ inch to $2\frac{1}{4}$ inch. The very largest of the materials used was $2\frac{1}{4}$ inches and not 3 inches. He recommended nothing larger than $2\frac{1}{4}$ inches.

The Chairman said that he should like to make a few remarks on Mr. Shenton's very valuable and interesting paper. His (the Chairman's) only practical experience of a septic tank was that he had had one fixed in Lincolnshire a short time ago, with the usual filter bed, and ran into it the domestic sewage from a large house, laundry, stables, and the usual offices. The effluent, however, did not show any good results for the first month or so. He presumed that the organisms took some little time before they began the actual work of the septic tank. It would be interesting to have some practical expression of opinion as to how soon the organisms actually began to work after the tank was started.

The author, in referring to the size of the materials in the beds, said: "Whatever differences of opinion exist, it is generally agreed that the first beds must not be of too fine a material, or they are sure to clog up." Then the author also stated that the Manchester Corporation had decided upon a $\frac{1}{8}$-inch mesh for passing the material through. The two statements did not tally. Perhaps the author would explain.

The question of grit seemed also to be an important point. He thought that it was not a difficult matter to keep grit out of the sewage with a little care.

Dr. RIDEAL said that he thought that the practical points of the paper were very important. Mr. Shenton had carefully distinguished between the work of the engineer and the work of the chemist and bacteriologist. He had dealt with the engineering portion of this important subject in a very careful manner, and had criticised the work at Manchester, Leicester, Exeter, Guildford, Ash and elsewhere in the way in which an engineer should criticise pioneer installations involving new principles. He (Dr. Rideal) regretted, however, that other engineers during the last four or five years had not also given similar criticisms. About four years ago he thought that England would be the pioneer country in the practical application of bacteria to the solution of the sewage problem, considering the earlier experiments of Mr. Scott Moncrieff, Mr. Cameron and Mr. Dibdin. They suggested certain methods of dealing with sewage by means of bacteria apart from chemical precipitation or land treatment, and at that time it looked as if English engineers would quickly adapt their practice to this new departure in the methods of sewage disposal.

During the last four years, although further experiments had been made, notably at Manchester, Leeds, London and Leicester, there had been practically no engineering papers in the country dealing with the engineering part of the problem. In the brewing industry engineering had advanced simultaneously with the work done by chemists and bacteriologists in that industry. In America and in Germany progress had been made in the bacteriological treatment of sewage by engineers on engineering lines, and information similar to that which had been given to the society this evening had been accumulated in both those countries and was being put on record. The Exeter scheme had been sanctioned by the Local Government Board, and the Manchester Corporation had at last agreed to the plans of the Local Government Board with regard to the bacteriological treatment of the sewage of Manchester. But that had taken a long time, and engineering papers on the

details of the question had not been forthcoming. For that reason he welcomed the paper of this evening.

He thought that they had arrived at a time when they could see distinctly that, for success, the bacterial treatment of sewage must be carried out in two distinct plants. The first must be designed to provide for a treatment of the sewage, which he would call hydrolytic. Biologists called it anaerobic, but in common English this first process might be called a breaking down of the solids. That ought, in his opinion, to be accomplished in a separate installation by a distinct plant, and the process ought to take place before they attempted the second main process, which was the oxidation of the solids in solution. He believed that the early attempts to mix the two distinct stages in one apparatus, or in a series of apparatus which alternated in function, was a mistake. He believed that the advocates of the Sutton or contact beds were beginning to see that it was necessary to differentiate in the way he had just pointed out. Therefore the problem which was to be dealt with by engineers consisted in designing installations in two distinct halves, and he believed that such division was a very great step towards success. Until the engineer gave details of construction of such dual installations, it was a mistake to criticise the contact bed adversely, because it was capable of doing its work efficiently. There was a sludging-up in certain places, but that could be overcome by resting the bed, and even if the sludging-up resulted in completely filling the bed, it was not so expensive to take the sludge out of the bed and burn it, or to wash the bed, or to relay it, as it was to make a new bed. But theoretically, and he believed practically, it was a mistake to allow contact beds to sludge up at all, and therefore they ought to be protected by a first-process hydrolytic tank. At the Southampton meeting last year there seemed to be a consensus of opinion that an anaerobic preliminary was an essential to success, and the recent reports from Leeds and the London County Council confirmed the view that he had held for some time.

With regard to the second kind of plant, after they had got rid of the solids and they came to the filter bed, the question was one of oxidation pure and simple. The essential of oxidation was that there should be plenty of air in contact with the liquid, and therefore the filter bed should be open, and should be arranged so as to allow the largest quantity of air to be in contact with the hydrolised and liquefied sewage. Many of the beds which had been put down had been defective, as the amount of air which could be introduced into them was less than that required to oxidise the ammonia, and the deficiency

of air was indicated by the small amount of nitrates which were found in the effluent. The deficiency of air was also shown in other filters by the absence of nitrates and the presence of large quantities of nitrites. Sufficiency of air was shown by the amount of nitrate in the filtrate being equal to that of the ammonia in the hydrolised sewage. As it was necessary in the second plant to have a proper supply of air, many inventors had devised means for effecting that, and the filters of Colonel Ducat, Scott Moncrieff, Whittaker-Bryant, and the Leeds continuous beds, were some of the more important designs which had been devised for that purpose. Colonel Ducat contended that his apparatus dealt with the solids as well, but in that respect he thought Colonel Ducat was wrong. Under the present Local Government Board regulations filter beds worked on the contact principle had to be full three times a day. That meant that there was a considerable part of the day during which those beds had no air in them, and he believed, therefore, that those beds during a large percentage of their existence were doing no oxidising work at all. He had held that view as to the filter beds for some years.

There were three points in the paper to which he wished particularly to draw attention. The first was with regard to the Leicester experiments. Those experiments were of a private nature at present and could not be discussed in detail. Mr. Mawbey's report had not yet been made public. Therefore a great deal of what he (Dr. Rideal) had intended to say with regard to Leicester must be left unsaid. At the same time he believed that Mr. Mawbey and Mr. Martin, who represented perhaps opposite views on the question, were both agreed that different towns might require different methods for dealing with the sewage problem. The Leicester farm was well known as being land which was admirably adapted for the final treatment of sewage, and when the cost of land and the cost of labour was high—and he supposed that it was as high in Leicester as in other towns—it was a question whether they should not utilise the land which the corporation had already acquired, instead of going to the expense of constructing large septic tanks and a series of filter beds for dealing with the sewage of the town.

The next point in Mr. Shenton's paper to which he would refer was that in which the author said, that it would be very interesting if there was further information respecting the black deposit. He states, "This black sludge has been often described. It has been compared to the ash which remains after the combustion of materials by fire, and has been called

the ash of sewage." The phrase "ash of sewage" was a very inaccurate one. It was, he believed, invented by Mr. Cameron, and Mr. Cameron had noticed that black deposit only in the effluent from his septic tank in which he (Mr. Cameron) contended there was no oxidation or burning, so that the term "ash" for that residue was misleading. The black substance was also formed in contact beds. He (Dr. Rideal) had examined it on several occasions and he believed that it was allied to humus, the black substance which formed in soil within the first few inches of the top. It was especially interesting because it contained nitrogen. The experiments made by Sir John Lawes and Dr. Gilbert in growing wheat on the same land without manure for a great number of years showed that the wheat continually grew year after year on the same land, and as wheat could not, like leguminous plants, absorb nitrogen from the air it must therefore get its nitrogen from the soil, and if the soil was not being manured the nitrogen must be obtained by the wheat from the black matter of the soil. The black matter contained nitrogen in a very stable form, but it slowly gave up its nitrogen to plant life. The black matter in the sludge which was formed in the septic tank was of the same character and contained nitrogen. Although it was nitrogenous and organic it contained a large quantity of mineral matter as the following analyses of deposits which he had obtained from the septic tank in Exeter showed :—

BLACK DEPOSIT AT EXETER.

—	No. 1.	No. 2.	No. 3.
Distance from bottom (inches)	3	9	15
Organic matter per cent.	32·35	32·40	31·31
Ash per cent.	67·65	67·60	68·69
Nitrogen per cent.	2·38	2·34	2·45
Percentage of N in organic matter ..	7·36	7·22	7·82
Microscopical characters.			

No. 1. Black amorphous matter, small sand particles, fragments of muscular fibre, dark coloured and corroded, and of other animal tissue; large amoebæ, cladothrix, micrococci and bacilli, fragments of faecal matter, vegetable tissue and hairs.

No. 2. Spiral vessels of a plant, anguillulæ, egg of an entozoon, fewer amoebæ, otherwise like the last.

No. 3. Anguillulæ, vegetable hairs and spiral vessels, faecal

fragments rather abundant, sponge spicules, animal hairs. No amoebæ and very few muscle fibres, otherwise similar to the preceding.

He (Dr. Rideal) had also analysed the black deposit from the first contact bed at Hampton (June, 1900), it contained :—

Water	7·18
Ash	48·37
Organic matter	44·45
	100·00
Total nitrogen	4·788
Percentage of N in organic matter	10·79
Organic nitrogen	3·058
Percentage of organic N in organic matter	7·12
Combined ammonia	1·73

The ash contained :—

Oxide of iron and mineral salts	17·00
Coke	4·18
Silicious matter	27·19
	48·37

The organic matter was therefore closely related to humus, and was similar to that formed in the septic tank. A microscopical examination showed large numbers of anguillulæ, with amoebæ, a few rotifers and flagellate infusoria, aquatic larva cases and portions of insects, a few animal hairs, possibly human, and some isolated fragments of muscular fibre, diatoms and desmids (synedra, etc.), vegetable debris, fragments of wood, epidermis, leaf hairs, ducts of ferns, spiral vessels, straw, and grass stems. A large quantity of dark-brown amorphous matter of humus character, crimson particles and dyed fibres, blue and orange, fragments of coke and coal, sand, and carbonate of lime crystals.

Still more recently he (Dr. Rideal) collected some of the black floating particles from Stoddart's continuous filter at Knowle, Bristol (September 28th, 1900). The total weight of deposit was 4·37 parts per 100,000 of effluent. It contained :—

Mineral matter	31·91
Organic matter	68·09
	100·00
Organic nitrogen	4·69
Combined ammonia	0·57
Percentage of organic N in organic matter	6·88

The microscopic examination of the above showed aquatic

larva cases, fragments of winged insects, numerous anguillulæ, crustacea (Daphnia), rotifers, infusoria (monas, paramoecium, vorticella); algæ (cladophora and species of conferva), cladothrix, beggiatoa, fungus-mycelium, black particles (probably coke), brown amorphous matter, silicious particles, vegetable hairs and fibre. That stuff was very stable. It did not smell, and it was harmless, and seemed to be a characteristic of most of the bacterial effluents which he had examined. Those who did not understand the subject thought that an effluent was bad if it had much of that black stuff in it, but nothing of the sort was the case. The black stuff was nothing worse than the black matter in the soil, and if necessary could be easily removed by a few inches of sand filter.

There was a third point which Mr. Shenton, as an engineer, was also very fair about, and that was the survival of the pathogenic organisms. He (Dr. Rideal) had dealt with the subject rather fully in his work on sewage, but there were a few experiments which he had carried out comparatively recently which had not been published, and which might be of interest to the Society. It was demonstrated by Dr. Houston in his examination of the intermittent filter-beds of the London County Council that the sewage organisms survived the filter. He (Dr. Rideal) therefore thought it would be of interest to specially examine the effluents from the filters at Caterham with a view to ascertaining whether the sewage organisms survived the oxidising influence to which they were subjected in their passage through the nitrifying trays, and he found that the number of organisms capable of growing on carbolised gelatine surface plates, amongst which the bacterium coli communis was found, were reduced from 2,180,000 per c.c. to 100,000 in the filtrate, from one of the sets of filters, to 50,000 in that from another, and 80,000 in the filtrate from a third, so that while the least efficient of the filters removed 95 per cent. of these organisms, the best filter removed 98·5 per cent. It would be seen on reference to the following analyses, that the greater the oxidation, as shown by the higher quantities of nitric nitrogen, the less number of sewage organisms remained.

He, Dr. Rideal, further found that although the addition of ·0001 c.c. of the tank effluent to a broth tube and incubated at blood heat for four days produced indol, the same dilution of the filtrate from D gave no turbidity or indol, whilst the filtrates from C and F, although producing turbidity, also failed to give any indol reaction.

The survival of spores of *B. enteriditis* was no less interesting, and would be best seen from the following table, where

(+) indicates the presence of such spores, and (−) their absence:—

—	Tank Effluent.	Filtrates.		
		C.	D.	F.
·01 c.c.	+	+	−	+
·001 c.c.	+	+	−	−
·002 c.c.	+	+	−	+
·0001 c.c.	−	−	−	−

The nitric nitrogen and the ammoniacal nitrogen present on November 10th, when the bacterial samples were collected, are shown in the following table:—

—	Tank Effluent.	Filtrates.		
		C.	D.	F.
Nitric nitrogen	Nil	5·48	11·6	10·96
Ammoniacal nitrogen	12·3	4·56	2·05	3·28

Dr. Houston had shown that, in an intermittent contact bed where there was alternately air and no air, *B. enteriditis* seemed to survive. Therefore there was a strong argument in favour of allowing the last process of the sewage treatment to be done with as much air as possible, and he (Dr. Rideal) maintained that that was not done properly in contact beds, but only by the continuously aerating filters, which had not been alluded to by Mr. Shenton in his paper. Some experts were adversely criticising the bacterial treatment of sewage because some of the effluents had not conformed to arbitrary standards of oxygen consumed and albuminoid ammonia, and also from the possibility of survival of the pathogenic organisms. But the proof of the pudding was in the eating, and if, as they had seen from the experiments at Manchester, the effluents from the filters actually purified the Ship Canal, and when they were incubated by themselves and put under the worst conditions they did not putrefy, and when the filters were well aerated, pathogenic organisms did not survive, he maintained that there was a very strong argument in favour of the well-designed bacterial filters as against land treatment. When they came to consider the cost, in most cases the cost of land was prohibitive. As an alternative, pipe lines had been suggested within the last few

months at Cardiff, Bradford and Leeds. But even the Manchester Corporation had gone in for the bacterial treatment with all the Local Government Board refinements and conditions at a cost far in excess of what a pipe line to the estuary would have been.

Mr. C. CHAMBERS SMITH congratulated Mr. Shenton on the excellence of his paper, which showed, he said, that he had brought very considerable thought and observation to bear on the subject, and although the bacterial system of sewage disposal was one with regard to which engineers generally were liable to fall into considerable error, the author had avoided many of the delusions which were prevalent on the subject. He, however, noticed that Mr. Shenton remarked that because a detritus tank had been introduced by him (the speaker) at Sutton on his own responsibility, due to the character of the sewage, in order to arrest detritus and floating paper, the term "Sutton system" was incorrect. This conclusion was equally as erroneous as it would be to assert that because double contact beds on the Sutton system had been introduced in some cases by Messrs. Cameron, Commin and Martin the term "Septic tank system" was incorrect. Local conditions which governed the character of the sewage should always be taken into account, and engineers should avoid, if possible, dogmatising and asserting that what would answer for one town would equally well answer for every other town in the kingdom.

Under many conditions he preferred that the sewage should be screened and run in a fresh condition directly upon the beds, and many of their bacteriological friends would advise them that this was preferable, and that to convert the incoming sewage into a septic condition before passing it on to the beds was not advantageous. One of the manifest drawbacks to detritus tanks was the offensive odour which was given off by the effluent on its passage from the tank and while the beds were being filled up by it, and this nuisance was so serious as to prohibit the adoption of this system whenever sewage works were in the neighbourhood of houses or public roads or footpaths. In such cases, and whenever the sewage was comparatively free from mineral matter, or did not contain paper in an uncomminuted condition, his experience was that screening was the better method to adopt.

He (the speaker) pointed out that the first coarse grain bed constructed by him at Sutton on the lines advised by Mr. Dibdin had now been working for over four years, and that it still continued to do its work in an eminently satisfactory manner, and Mr. Shenton's observation that the "Sutton bacteria beds became clogged" was incorrect. He had always

held that the capacity of fine grain beds should not be so large as that of the coarse beds, as a cubic foot of material of the second bed had a greater liquid capacity than a cubic foot of material in the first bed. The reason of that was that after a few weeks' working, owing to the accretion of organic matter around the nodules of the material forming the first contact bed, its capacity was reduced to from 25 to 33 per cent., and it then maintained this capacity in general for an indefinite period. The suggestion that the work of the second bed should be increased by giving it foul sewage or some sludge from the first bed was not to be recommended, and was made, he thought, without a knowledge of the distinctive work carried on by the two beds. A more practicable solution he would suggest was to increase the capacity of the first contact beds to at least 15 per cent. greater than the second contact beds.

He could not agree that the placing of fine material on the surface of a first contact bed was beneficial. It was said that it arrested the sludge on the surface. But that was just what should be avoided. The sludge was required in the body of the bed where it could be acted on biologically and destroyed. Bacterial action was carried on in the dark, and not on the surface exposed to light. Moreover, the fine material prevented that free access of air which was so essential to the action of the organisms. An instance had been given by the author where a small area of the bed near the sewage inlet had been covered with fine material, to arrest the sludge which it was said could easily be cleaned and the sludge removed. But that was a step backward, for the whole purpose of the beds was to destroy the sludge and not to temporarily arrest it so that it should be subsequently removed and treated elsewhere.

He (the speaker) also dwelt upon the materials most suitable for the beds and to the several systems of continuous filters which had been put forward, and which were claimed to have advantages. Engineers, however, in guiding local authorities as to the relative advantages of the various systems had to consider the all-important one of cost, and second that of efficiency combined with control, and as regarded the latter condition it was present in both of the two systems described by the author. He had constructed beds at Sutton of a depth of 3 feet, costing 3*s.* 6*d.* per yard super, and that could not be deemed excessive.

Mr. G. Thudichum said that Dr. Rideal had contended that it was absolutely necessary to have an anaerobic commencement of the process of treatment. He had, in fact, gone so far as to maintain that hydrolysis and anaerobic action were convertible terms. That was the point upon which Dr. Rideal and he

(Mr. Thudichum) split. He would not argue the question. The Sutton aerobic beds might be wrong in conception, faulty in construction, and absolutely incorrect in principle; but they gave an admirable effluent, and, as Dr. Rideal had said, the proof of the pudding was in the eating. The Sutton system would be found at a great many other places throughout the country, and there was not a preliminary tank in all cases. Dr. Rideal had told them that he had long held the same opinion without alteration. He (Mr. Thudichum) would not say that he had formed new opinions during the last three years but he had modified his old ones, and he knew that the septic tank was of the utmost possible value, and even more so from the engineering than from the biological point of view. Its great value, in his opinion, was that they got the purification with one fall. In many cases that would save a pumping plant.

There were, however, cases in which the septic tank was of absolutely no use, as, for instance, in the attempt to deal with the refuse of a whisky distillery. In such a case the suspended solid matter amounted to about 2000 grains per gallon, and the septic tank would not dissolve that matter in anything like reasonable time. There was also a production of organic acids which made it impossible to treat the effluent on an aerobic bed afterwards. But if the refuse was taken while fresh and put over a succession of aerobic bacteria beds the stuff could be purified. He had himself grown salmon fry from ova in the effluent produced from distillery refuse by that process.

The amount of work which should be done by a first contact bed as compared with the second had been mentioned by Mr. Shenton. The point was a very important one, and it was one to which Mr. Dibdin and he (Mr. Thudichum) had given a great deal of thought. They had gone so far as to suggest that a bed of very coarse smooth material which would admit of a washing out as each charge came out would probably be of great advantage, and they had tried it. They had found that they did less work on the coarse bed than on a bed of burnt ballast or coke, and they did more on the second bed; but the result was the same. The advantage, however, of this plan was that it enabled the suspended matter to be put upon the bed in greater quantities, and perhaps at more frequent intervals. He would only say in conclusion that he thought that Mr. Shenton deserved the greatest possible credit for the admirable way in which he had brought the subject forward.

Mr. Mawbey said that he was afraid there was an impression that there was a very much greater chasm between the septic people and himself, than really existed. He did not

think that he had proved absolutely that no septic action was necessary. He would remind the meeting that he had always, from the first, advocated a detritus tank, and at Leicester they believed it to be necessary. At Leicester they had also some septic action which had proved to be of advantage, but they had found that they did not need the septic system in its entirety. Everybody got some septic action, first of all in the sewers if the sewage had long distances to travel, and a little more septic action was obtained in the detritus tanks. He had recommended detritus tanks in the new scheme for Leicester. He had found that it was better not to have an extremely advanced putrefactive condition of the sewage, and that it was much better to effect the clarification in a first contact bed, after subsidence, in a detritus tank before the passage of the sewage to the land, than to adopt the septic system for that purpose. The clarified effluent from a detritus tank of pretty large capacity, passed through a coarse bacteria bed, behaved much better on the old pasture and rye grass of Leicester than did the effluent from a complete septic system.

But, as had been wisely said, what was the proper thing for Leicester might be totally unsuitable for another town. Each town must be dealt with upon its own merits. The sewage of different towns differed so widely that, even if the physical condition of two towns were alike, it did not follow that the same scheme would suit the two places. At Leicester they had a splendid sewage-farm area, and therefore they had no need to go in for a complete bacterial treatment. All they wanted was a clarification of the sewage before it was passed on to the land.

Mr. R. A. MacBrair said that he had been constructing bacteria beds for several years. He began by running crude sewage through bacterial beds, but that gave them too much work to do. Now he had chemical tanks for about four-fifths of the flow. The tanks were filled all day and run off early the next morning. When he was constructing one of his bacteria beds a well-known authority happened to come down and expressed great admiration for them, but said, "You are putting in the coke in your first contact beds too small. You can scarcely make it too big." In deference to that opinion he began laying down larger coke, but he had found that that was a mistake. He did not know the reason of the failure, but perhaps it was due to the fact that when the pieces of coke were larger, the interstices were greater, and it might be that a certain amount of the sewage did not come into contact with the coke at all.

He differed from the view of the author of the paper that

the cost of material was a very minor point in the construction of bacteria beds. In fact, it was the greater part of the cost. He was now paying 17*s.* 6*d.* a ton for coke; when broken that made from 35 to 40 cubic feet, and therefore cost about 10*s.* per cubic yard, independently of the cost of breaking and cartage. That amounted to about 1200*l.* for the coke for a half-acre bed 3 feet deep, and that would be considerably more than the walls, floor, pipes, valves and other things.

He had constructed a system of wooden channels with 3-inch rain-water pipes leading out of them. Those pipes had ½-inch holes about 12 or 15 inches apart, and by that means he was able to form a sort of cascade of the sewage of from 3 to 7 inches, according to the head of sewage. That helped to vary the incidence of the sewage upon the coke, and aeration was obtained at a very cheap rate. He was now making wood troughs, 12 inches by 10 inches internal size, with sloping ½-inch holes made in each side at the bottom; that gave a cascade action of about 12 inches.

Dr. KENWOOD said that Dr. Rideal had taunted them somewhat with the opinion that English engineers had not kept pace with chemists and bacteriologists in the biological treatment of sewage, but he (Dr. Kenwood) did not agree with that opinion. He thought that the scientific men who were concerned with the biological investigation of the sewage problem, were by no means in advance of the engineers. The scientific man had experienced no difficulty in getting their suggestions applied practically by engineers, and he must confess to them that they had still a tremendous amount to learn. He believed that at the present stage the engineer had done all that he could, and it remained for the chemist and the biologist to indicate the direction of further advances.

There was no doubt that they must separate the stages of purification, and with reference to that point the author of the paper had asked the question: "Is it not worthy of consideration whether an attempt should be made to let some of the foul sewage, which tends to sludge up the first bed run on to the second?" Mr. Shenton asked the question because the coarse bed got clogged and had to do an amount of work which was quite disproportionate to the amount of work which the finer beds had to do, and he suggested that the first coarse bed might be relieved by letting some of the coarse sewage go upon the finer bed. He (Dr. Kenwood) believed that that would be a very wrong thing to do. The purification went on in stages, and the organisms became differentiated in the different stages, and he had no doubt that by letting down some crude sewage upon the finer secondary beds, the action of the latter beds would be seriously disturbed.

As to the question raised by Mr. Thudichum whether a preliminary anaerobic treatment of the sewage was essential to final purification, he (Dr. Kenwood) was of opinion from experiments which he and Dr. Butler had been making that such was not essential. They had taken samples of crude sewage, and exposed half to the external air in a large dish placed on a window ledge outside of the laboratory at University College and put the other half into bottles and kept them under as perfectly anaerobic conditions as was practicable, and for a long period the results of the analyses of both sets of samples remained remarkably similar. Those experiments seemed to point to the conclusion that an anaerobic stage was not an essential preliminary to the natural purification of sewage. Doubtless a great deal of unnecessary confusion had been imported into the question, and a great deal of nonsense had been written and spoken in reference to the relative powers of so-called anaerobes and aerobes. There was no doubt that under different conditions aerobes became anaerobes and anaerobes were aerobes. Sewage organisms to a large extent adapted themselves to their environment, and even aerobic organisms were found in the anaerobic septic tank.

With reference to what Mr. Shenton pointed out as to the advantage of secondary beds, there was no doubt that the aerobic bacterial beds were very expensive indeed if they were properly made, but he had no doubt that there was a tremendous gain in multiplying the fine bed, though there might be but one coarse bed for a preliminary. The repetition of fine filters so that the effluent from a coarse bed, a septic tank, a Scott-Moncrieff cultivation chamber, etc., could be led through two or even three fine beds, with comparatively short periods of rest, not only produced a more highly purified effluent, but did so in a shorter period of time. In other words, change of bed produced better results in less time than a prolonged rest in the same bed. He had satisfied himself on that point.

Mr. Shenton said "The Septic Tank Syndicate arrange that their system shall work entirely automatically, and the advantages of automatic working cannot be too highly appreciated." That was a view which they would all endorse. It was one of the respects in which the Septic Tank Syndicate had done very important and valuable work. They had given us an ingenious device for the automatic working of the bacterial beds. It seemed to be necessary to exclude as far as possible the human element from the bacterial treatment of sewage. He had been struck with the fact that in the majority of cases coming to his notice in which failure had resulted, that failure had been due to the introduction of the human element. One had to bear in

mind that the organisms fed on sewage and that they ought to be fed at regular intervals, and allowed to have a proper period for rest or digestion. If their meals were given to them irregularly, or if they were overfed, they would get the same complaint that human beings often got under the same circumstances, namely, flatulent dyspepsia; and then the bacteria beds would give off bad odours. The analogy was a great deal closer than it might appear to be. The products which accumulated at the bottom of the septic tank were closely analogous to the undigested material found in human faeces. He had known instances in which the beds had to be stopped for two or three months to give time for the digestive powers of the bed to be recovered and for their purifying action to be regained.

Mr. R. F. GRANTHAM said that he had had to construct works for dealing with the sewage of a town in which brewers' refuse constituted about one-third of the whole discharge of the sewage. The author, referring to the question of brewers' refuse, said, "In this matter engineers may save themselves great trouble if they can get the brewers to filter their waste." As far as his (Mr. Grantham's) experience went that was exactly what brewers could not be induced to do. In the town to which he had referred there were two breweries, and the brewers were the most important people in the place. They claimed a vested right to run their refuse into the sewers, and they said that they did not mean to do anything else, and that the town authorities must deal with the refuse as they could. He first designed tanks for the chemical treatment of the sewage, but after the designs had been submitted to the Local Government Board the members of the district council went to see the bacterial treatment at Sutton, and they were so satisfied with it that they instructed him to adapt the designs which had been prepared, to the bacterial treatment. The adapted scheme had been working for a year and a half, and it had had to deal with from 160,000 to 400,000 or 500,000 gallons a day. The whole of the sewage had to be pumped up. There were two sets of tanks, one of coarse beds and the other of fine beds, and five acres of land. The effluent from the lower or fine beds flowed on to the land and disappeared and was never seen again, and so the council escaped the clutches of the Thames Conservancy. He had no doubt that with a detritus tank, but not a septic tank, bacterial treatment would afford a means of dealing with brewery refuse provided the tanks were large enough. He did not think the tanks under his charge were quite large enough. When they were made he was under the disadvantage of not knowing quite what proportions to make them. He did not, however, think that it would be

necessary to make them quite so large as the Local Government Board had since that time prescribed.

Mr. Alfred Hanssen said that as chief assistant to Messrs. Shone and Ault he had had something to do with the Hampton tanks. The author stated that the material in the first tank was retained by a half-inch mesh. That statement was somewhat misleading, because the half-inch mesh would retain pieces as big as one's fist. The fact was, that the material was probably bigger than was wanted, and certainly bigger than was specified. The top layers of the tank were very large indeed, being nearly as big as two fists, and as far as he knew the layers were nearly of the same size right through. He believed that the action of the first bed would have been better if the material had been somewhat smaller. At present they got some black sludge in the channels. Mr. Shenton mentioned that gutters with perforated covers were very good for collecting channels. They had been using such gutters at Hampton in the bottom of the tanks and they worked very well indeed, but there was an accumulation of sludge in the gutters of the first bed, which it was somewhat difficult to purify, and most of that sludge flowed to the second bed, where the effluent still contained some sludge and was not quite free from decomposition. Effluent water was used for the surface condenser of the steam air compressor, which supplied air for lifting the sewage, and that water was sometimes taken from the second bacteria bed, but it was found to give off some smell. The effluent from the third bed, however, was quite free from smell, and was exactly like a potable water. Dr. Rideal had mentioned that black deposit was removed from the filters, but he was not quite sure whether Dr. Rideal meant that the black deposit was taken from the surface of the first bed.

Dr. Rideal said that he was speaking of the sludge that came from the first bed, and which went into the channel and would go on to the second bed.

Mr. Hanssen said he wanted it to be understood that no such large quantity of sludge, as mentioned by Dr. Rideal, was removed from the surface of the bacteria beds. Every time he had been to the Hampton works, the surface had been quite undisturbed, although he understood that some raking and weeding was done, and that some paper pulp was removed; but the surveyor, Mr. Kemp, allowed a certain amount of vegetation to remain in order to demonstrate how very little attention the bacteria beds required.

Mr. E. J. Silcock said that he should like to say one or two words with regard more particularly to the septic tank

effluent when it was dealt with without contact beds at all. The author of the paper had referred to the experiments made by Mr. Mawbey at Leicester, and he rather pointed to the conclusion that, because those experiments had not been very successful, therefore the effluent from the septic tank could not be applied to land at all. He (Mr. Silcock) ventured to think that that was a conclusion which would not be endorsed by everybody. He did not think that Mr. Mawbey's experiments were altogether conclusive on the point, nor were they intended to be. Mr. Mawbey tried the application of the effluent from a septic tank on pasture land for surface irrigation only. Dr. Rideal had suggested that the Leicester sewage farm was very suitable land for irrigation purposes, but he (Mr. Silcock) did not quite agree with that view. At all events, it could not be said to be the sort of land which was suitable for filtration purposes. It appeared to him that if the effluent from the septic tank was applied to land which was suitable for filtration purposes, it was probable that they would be able to utilise the effluent in that way and obtain good results. That was a point which was much more important than it appeared to be on the surface, because the cost of the contact beds was very prohibitive. They had been told by Mr. MacBrair that the cost of material in the rough beds was 10*s.* a cubic yard, and he could quite confirm that figure. As to clinker, it might be bought cheaply in small quantities, but as soon as a demand was created for thousands of cubic yards the price was raised.

There were, of course, features about the septic tank which, from an engineer's point of view, were especially favourable. One of them which had been alluded to was that there was no loss of fall. That was an extremely important question, especially in small installations. There was the further advantage that the septic tank itself, without a filter was entirely automatic, and needed no machinery of any kind. Those two features, combined with the small cost as compared with the contact bed, made the septic tank especially adaptable for dealing with the sewage of small communities, and when funds were limited.

He did not think that the question whether or not the septic tank would sludge up was definitely settled yet. The Leeds people had been experimenting for three years, and still the resident chemist and the resident biologist had not come to very definite conclusions. The only thing which they had decided was that they must have some land, and the corporation had actually purchased an estate of 1800 acres for the purpose of utilising the sewage upon it. Further experiments were required.

As to towns in which there was manufacturers' refuse, there was no question that contact beds would and must sludge up to a certain extent. The sewage ash, of which they had heard, was present to a certain extent, and the filtering material was bound to sludge up in time. The only question was in how long a time. But if there was a septic tank, it would be possible to remove the sludge without emptying the tank. On the other hand, if they had a contact bed, half the material after being removed would be unfit to be put back again, and the process would be very costly. That was another point in favour of septic tanks.

Dr. W. Butler said that most of the speakers had referred to the importance of anaerobic action in the biological treatment of sewage. Mr. Shenton had very wisely abstained from giving an opinion as to the merits of that treatment. Strictly speaking, sewage was not subjected to the action of mere anaerobes. The time which sewage took to pass through a septic bed or an anaerobic tank was not sufficient to permit of all the organisms in it being converted into anerobes. As Dr. Kenwood had pointed out, many might be facultative for the time being, but the sewage was not subject entirely to their action.

Dr. Rideal had contended that a hydrolytic treatment was essential, but he had not told them why. He (Dr. Butler) believed that it was needed for breaking down the suspended matter. He granted that the suspended solids in order to be liquefied and broken down must undergo anaerobic action. It yet remained to be proved that any good accrued to the sewage itself from undergoing the same process, and he thought that facts proved, that for the treatment of the liquid sewage anaerobic action was unnecessary. Sewage could be purified without such action, and it showed a preference for aerobic purification. Dr. Kenwood had referred to the experiments which he and himself (Dr. Butler) had made by keeping sewage in stoppered bottles free from contact with air. Some of the crude sewages, without any treatment whatever, were found in the course of months—even twelve months—to have undergone very extensive nitrification. Nitrates to the extent of 5 parts in 100,000 were formed in sewages which originally were free from nitrates, and which had been kept under such anaerobic conditions as were afforded by keeping in glass-stoppered bottles. If sewage showed such a predilection to nitrification as that, it was wrong to subject it to any treatment which tended in the distinctly opposite direction. He took it that the object of sewage purification was to get an inoffensive effluent; but the first effect of anaerobic treatment was to produce an offensive decomposition. It seemed to him that

the anaerobic treatment which was necessary for the resolution of the suspended solids had yet to be proved to be necessary for the treatment of the liquid sewage itself.

The following communication, received from Professor HENRY ROBINSON, Past President, who was unable to be present, was read:—

I have read Mr. Shenton's paper, and desire to contribute the following remarks:—It was in 1877 that MM. Schloesing and Muntz (two French chemists) published some interesting experiments in regard to the breaking down of organic matter into simpler products, which had hitherto been considered as the result of oxidation. Mr. Robert Warington at that time gave the outcome of his observations at Rothampstead, in papers to the Chemical Society, the British Association and the Society of Arts. He pointed out that the changes which were effected in sewage, by passing it through land, were produced by a nitrifying organism, and not by oxidation. The experiments that were made by the Massachusetts State Board of Health at their station at Lawrence, from 1888 to 1893, contributed valuable data in the same direction, and engineers realised that the question of sewage disposal had entered upon a new phase, which indicated alternative methods to those that had hitherto obtained, namely irrigation and chemical precipitation. I appreciate what has been done by those whose names are now associated with the bacterial treatment of sewage, and I have availed myself of the researches of the earlier investigators referred to. I may instance the case of a small town that I had to sewer about fifteen years ago, where the sewage had to be disposed of on an exceedingly small area of land, otherwise chemical treatment would have had to be resorted to. I adopted the plan (which I term the cesspit system) of discharging the sewage into a chamber, from which air and light were excluded, and relied on the solids being liquefied therein as in a cesspit. I arranged the chamber so that after the sewage had passed very slowly through, it was conveyed to the outfall plot for filtration. The result was entirely successful, the solids were liquefied (by what we now call anaerobic organisms), and the fluid was in the best possible condition for agricultural purposes.

In a more recent case I have passed the crude sewage into an anaerobic chamber in which I provide ample surfaces for the cultivation of the organisms by suitable materials, and the fluid from this chamber is conveyed for final treatment on to small plots laid out to receive it intermittently, by means of automatic gearing actuated by the flow of sewage. In another

case I have arranged to utilise both the anaerobic and the aerobic germs by passing the sewage first through a chamber from which air is excluded, and subsequently passing the fluid intermittently through aerobic beds.

I have found by experience that it is necessary to consider each case and its surroundings before the best plan could be decided upon. Where suitable land is available on which the fertilising properties of sewage can be utilised for agricultural purposes, with good financial results, I would not carry the bacterial system as far as would be necessary where no such land was available. I may mention apropos of this point, that I was asked quite lately whether I was prepared to confirm the advice that had been given in a certain case, that the bacterial treatment of sewage was the only way. My answer was that until the circumstances of the town were known, an opinion of that kind could not be given unless the question included the bacterial action which takes place in the soil, termed by Mr. Warington nitrification. Some important researches have been carried out in recent years on this branch of the subject in St. Petersburg, and Mr. Warington brought them before the Chemical Society this year. His paper deserves mention in this connection.

It would unduly extend my remarks were I to go into details as the author has done, but I desire as an old member of the Society to offer some remarks on Mr. Shenton's paper, especially as I am quite of opinion that the bacterial treatment of sewage is the solution of many of the difficulties that engineers have to deal with. I stated my opinion at the Institution of Civil Engineers in 1897 that the bacterial disposal of sewage "had come so much within the range of practical engineering that the days of sewage farms, and the distribution and purification of sewage on large areas of land were over, unless the sewage could be utilised with commercial advantage."

Mr. Shenton, replying upon the discussion, said that being an engineer and not a biologist, he had left the biological part of the question alone in his paper and must do so also in the discussion.

Of course he could only express considerable regret that he had misunderstood Mr. Mawbey's wishes with regard to the Leicester report. He had always considered the report referred to, a public one. As Mr. Mawbey had discussed the few references made to his report, he (Mr. Shenton) supposed he might be allowed to answer the criticisms made.

He had not by any means mistaken the Leicester detritus tank for the larger septic tank, as Mr. Mawbey suggested. No

doubt he ought in his paper to have explained that in his opinion such a detritus tank was a small septic tank. It was similar to the tank at Sutton which held only one-fifth the daily flow and, whatever it might be called, acted as a septic tank and acted well, no sludge being accumulated. The detritus tank at Leicester held 18,680 gallons of sewage, and was therefore no small catch-pit. It was to be noted that this detritus tank did not differ in construction from a septic tank, and that sewage passed through it in exactly the same way as it would pass through an ordinary septic tank. He could have said more apropos of the septic tank at Leicester, but he refrained from quoting the report since Mr. Mawbey implied that it was not a public one.

With regard to the Chairman's question—as to how the recommendation of the Manchester experts, that the material on the first contact beds should be retained on a $\frac{1}{8}$-inch mesh, agreed with his (Mr. Shenton's) assertion that it was generally admitted that first beds must not be of too fine a material—he could only say that it was probable that the Manchester experts did not expect to find very much of the small material in the first beds. The clinker recommended was certainly to be held on a $\frac{1}{8}$-inch mesh, but it was also specified to pass a $1\frac{1}{2}$-inch mesh, so perhaps it would be fair to regard the average size as $\frac{3}{4}$-inch. The Chairman had asked a question as to the time that it took for the action to begin in a new septic tank. He (Mr. Shenton) believed that it generally took some weeks before the action became really satisfactory. That action might be accelerated by putting in scum from an existing tank.

Dr. Rideal and Mr. Chambers Smith had both asked why he (Mr. Shenton) had not dealt with the continuously aerating filters. The reason was that where he had encountered them they did not appear, from an engineer's standpoint, to give satisfactory results. As an instance, he would ask Mr. Chambers Smith whether it was not the fact that the continuously aerating filter at Sutton had proved very unsuccessful. He was very interested to note Dr. Rideal's statement that, from the point of view of the bacteriologist, continuously aerating filters were of great importance.

He regretted he had not made himself clear as to the clogging of the beds at Sutton, and that Mr. Chambers Smith took exception to the expression. What he meant to imply was that the beds at Sutton became unduly clogged with sewage before the detritus tank was used, not that they became clogged up so as to be unfit for use. Of course, a bed might become clogged, or partly clogged, and recover with a short rest. He believed Mr. Chambers Smith had mistaken his

meaning as to fine material on the surface of beds. Both Mr. Chambers Smith, in his remarks, and he (Mr. Shenton), in his paper, looked upon fine material on the surface of first contact beds as a mistake. In fact, they were in agreement on the point.

The arrangement Mr. Chambers Smith condemned, viz. a small area of the first beds prepared so as to intercept paper, etc., might be seen working very well at Hampton. It did not appear that the arrangement arrested sludge in such a manner that the small area often needed cleaning. It would appear that the clinker ridge described in the paper broke up rather than detained the sludge. He quite agreed that sludge should not be arrested on the surface of the beds, and had said so in his paper. He would recommend Mr. Chambers Smith's statement, that the bacteria beds at Sutton cost 3*s.* 6*d.* per square yard, to the notice of those who had dwelt on the excessive cost of bacteria beds. There were plenty of instances of cheap beds.

He was extremely interested in what he gathered from Mr. Thudichum's statement that, as a result of his and Mr. Dibdin's experiments with a very coarse and easily washed-out first contact bed with second bed treatment to follow, less work was done by the first bed and more by the second, with a final result the same as if the beds had been made according to usual practice. Mr. Thudichum had shown that the advantage of the plan was, that it enabled more suspended matter to be put in the bed at more frequent intervals, or in other words, that it lessened the chance of the first beds clogging up. He (Mr. Shenton) would therefore once again, having received encouragement in the idea from Mr. Thudichum, appeal to those interested in the subject to carefully consider the idea of a very coarse, well-drained first bed as stated in his paper.

Mr. MacBrair seemed averse to the use of large coke for contact beds. Without attempting to deal with the question biologically, he would merely refer to Mr. Thudichum's remarks apropos of the subject, and suggest that perhaps Mr. MacBrair would find better results from large coke if he made his second beds of fine material and his first beds of large coke.

With regard to the cost of material for beds, he had known it vary considerably. At one place they could perhaps burn the clay excavated in forming the beds, as at Sutton. In another there might be abundance of stone of a suitable character, and so on. It was often possible to make the beds at a cheap rate by using the materials at hand. However, even with materials at a high price, the cost of making bacteria beds would compare very favourably with the cost of a large area of land that would do the same work. Besides, there was so great a saving

in labour that it made the cost of the beds a matter of small importance if regarded fairly.

He had already replied to the points raised by Dr. Kenwood (without going into the biological aspect of the case) in dealing with the points raised by other speakers. He was very interested in Dr. Kenwood's opinions on the biological questions, and especially in the circumstance that Dr. Kenwood did not consider anaerobic treatment essential to the purification of sewage.

He could, from personal observations made at Hampton, agree with Mr. Hanssen's assertion as to the beds there. He had seen vegetables, etc., growing on the first beds in use, showing how very little attention the first beds required.

He did not agree with Mr. Silcock that it was an easier matter to empty a septic tank than to clean a clogged bacteria bed. He compared the description of the emptying of the Leicester tank with the description of the cleaning of a clogged bed at Crossness, in published reports. In the one case there was an account of a most offensive proceeding, and in the other the bed was merely allowed to stand and rest for a few weeks and purified itself completely. As a rule it would not be necessary to take material out of a clogged bed to clean it, but if that had to be done, he did not quite follow Mr. Silcock's statement that half the material would be unfit to be put back again. He ventured to think that in the case of good, hard clinker, or other durable material, all might be replaced.

The following communication was received subsequently to the reading of Mr. Shenton's paper, from Mr. John Kemp, the borough surveyor of Hampton, Middlesex:—

I am informed that, during the discussion on Mr. Shenton's paper on "Recent Practice in Sewage Disposal," lately read before the Society of Engineers, reference was made to the black sludge which was stated to come from the coarse beds at Hampton in considerable quantities, and to be deposited on the second beds. The actual facts are as follows:—

About one cubic yard per week of a black, fatty substance comes from the coarse beds and is deposited in the distributing channels of the second beds, and so prevented entering the body of the bed. On one bed, upon which there are no distributing channels, this matter collects evenly over the surface, and is easily picked off with a shovel or a fork when dry. My own opinion is that this substance consists largely of the products of combustion in the coarse beds, together with myriads of dead

black insects which get washed from the surface to the interior of the bed. These black wingless insects, as observed through the microscope, are tremendous scavengers, existing on the surface of the bed to a depth of 6 inches, where they feed and fatten. The total matter removed, as already stated, is not more than 1 cubic yard per week. This deposit, I take it, is common to all similar processes, and even in the septic tank, from which it is more difficult to remove and separate from the liquid.

RECENT PRACTICE IN SEWAGE DISPOSAL.
By H. C. H. SHENTON.

PLATE I.

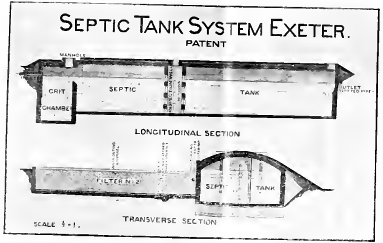

Fig. 1

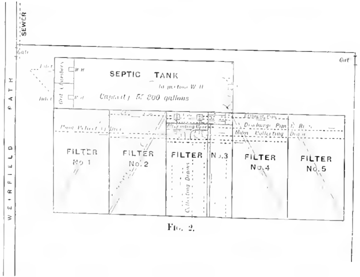

Fig. 2.

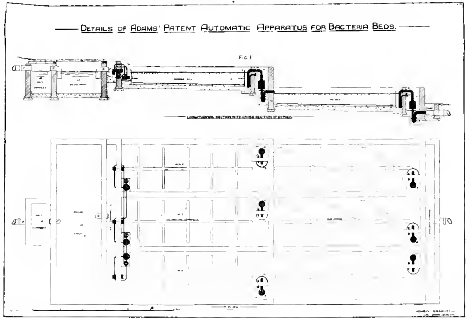

Fig. 3.

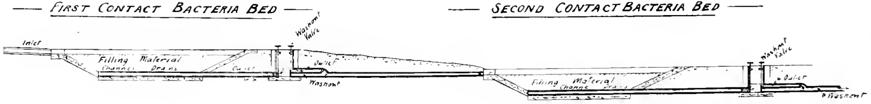

Fig. 4.

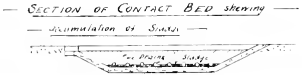

Fig. 5.

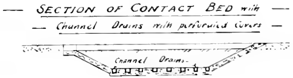

Fig. 6.

PLATE II.

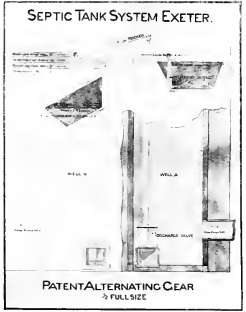

FIG. 7.

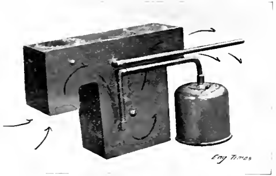

FIG. 8.

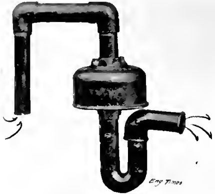

FIG. 9.

FIG. 10.

FIG. 11.

Obituary.

Thomas Hancock, who was born in 1845, died at Linares, Spain, in November 1899, but his death was not reported until the present year. Mr. Hancock was elected a member of the Society in May 1891, at which time he held the position of chief engineer to the Linares, the Fortuna, and the Alamillos lead mines at Linares, and which position he occupied at the date of his death.

Samson Jordan, whose death occurred in Paris on February 24, 1900, was born in Geneva on June 23, 1831. After completing his education in the technical schools he became engaged in engineering and metallurgical pursuits. At an early period of his life he entered the works of the Société du Gaz et des Hauts Fourneaux de Marseille et des Mines de Portes. In 1855 he constructed the Saint-Louis blast furnaces, near Marseilles, of which works he was for some years engineer and manager, and subsequently became a director. The blast furnaces at Saint-Louis were the first in France erected for the purpose of smelting the pure rich iron ores from Elba, Spain and Algeria, with coke as a fuel. To M. Jordan is due the credit of having introduced into France iron and manganese ores from Spain and the Mediterranean coast, and also of producing a special high quality of cast iron. In 1862, M. Jordan removed to Paris where he continued his professional work, performing also the duties attached to his position as engineer to the board of the Saint-Louis blast furnaces, the Marseilles gas-works, and the Portes coal-mines. In 1865 he was appointed professor of metallurgy at the Ecole Centrale des Arts et Manufactures, of which establishment he was formerly a pupil. He held the appointment of professor up to the time of his decease. M. Jordan occupied a distinguished position as an engineer and metallurgist, and during his life he in numerous ways assisted in the advancement of the iron and steel industries of France. He was the author of several valuable metallurgical treatises, specially pertaining to blast furnace practice. He was vice-president of the Comité des Forges de France. In 1874 he was elected president of the Société des Ingénieurs Civils de France, of which institution

he was an old member. He was also a member of the leading technical societies of France. He was likewise a member of the Iron and Steel Institute of Great Britain, and of the Imperial Institute. M. Jordan was elected an honorary member of the Society of Engineers in 1874.

Arthur Comber, who was born at Kidderminster in 1851, died in that town on May 26, 1900. After a preliminary education at Pearsall's Grammar School, Mr. Comber completed his education at Cooper's Hill Engineering College. He was afterwards articled to Messrs. James Binnian and Sons, builders and contractors, of Kidderminster. In 1873 he was elected borough engineer and surveyor to the Corporation of Kidderminster, which position he held at the time of his death. During his long tenure of office Mr. Comber designed and carried out numerous improvements, sanitary and otherwise, in his native town, earning the high esteem of his fellow townsmen. Mr. Comber was elected a member of the Society in 1879.

James William Smith, whose death occurred in Bombay on July 21, 1900, was born on July 14, 1839, at Ramsgate. After receiving a general education he was articled to his father, Mr. William Edward Smith, architect, civil engineer, and surveyor, of Ramsgate, with whom, both during his term of pupilage and subsequently, he was engaged on various public surveys and architectural and engineering works in Ramsgate and the neighbourhood. In 1877 the deceased gentleman went out to India to take up a municipal appointment, and the following year he was appointed assistant resident engineer to the Municipality of Bombay, and was engaged on the drainage of Bombay, and the construction of the Tulsi Water-works and the Malabar Hill reservoir. Mr. Smith was afterwards appointed special drainage engineer to the Bombay Municipality, which appointment he held at the time of his death. The deceased gentleman was connected with all the drainage works of Bombay since 1879, and he also furnished valuable reports on various recent drainage schemes. Mr. Smith was elected a member of the Society in 1874.

Burroughs Dickie Kershaw, who was born at Stoke Newington in 1830, died at Seaford on October 6, 1900. Mr. Kershaw was educated first at Wanstead and finished his education at the Putney Engineering College, in company with some who subsequently were the founders of the Society of Engineers. He was afterwards engaged with Messrs. Rendle, of Pall Mall,

on the Bradford drainage and water-works schemes, and the Southampton drainage. In 1856 Mr. Kershaw joined the staff of the New River Company, and was engaged with that corporation over forty-three years. For many years he was auditor to the Colne Valley and the Lambeth Water-works, and latterly was a director of the Lambeth Company. Mr. Kershaw was elected a member of the Society in 1859.

Lord ARMSTRONG was born at Newcastle-on-Tyne in 1810, and died on December 27, 1900. He was educated at Bishop Auckland Grammar School, and while in that town became acquainted with Mr. Ramshaw, who owned some engineering works, in which he spent much of his spare time. On leaving school he entered the office of Mr. Donkin, a Newcastle solicitor, and completed his legal studies in the Temple. In 1833 he returned to his native town, and became a junior partner in Mr. Donkin's firm. But the tendency of his mind was always towards mechanics and science, and these ultimately diverted him from the law. Turning his attention to electricity and the utilisation of water power, he first produced a hydro-electrical machine, and then a hydraulic lift. The Newcastle Corporation ordered two of these lifts, which were successful in operation, and in 1847-48 the Elswick Works for the construction of hydraulic machinery was started. Lord (then Mr.) Armstrong finally quitted the law and devoted himself entirely to engineering, developing the Elswick works and manufactures. His special attention was given to hydraulic machinery, and subsequently to gunnery, the Armstrong breechloading gun, first produced in 1854, with its subsequent detail improvements, being one of the most important results. In 1856 a Parliamentary Committee reported strongly in favour of the Armstrong gun, and its inventor presented his patents to the country. The Queen conferred on him a C.B., and he was appointed engineer of Rifled Ordnance, and subsequently superintendent of the Gun Factory. Woolwich was unprepared for constructing the new weapons, and the Government entered into a contract whereby they were to be made on the Tyne, and thus the Elswick Ordnance Company came into existence. This arrangement continued until 1863, when Sir William Armstrong resigned his appointment, and the contract was cancelled by mutual consent. To the manufacture of ordnance, the Elswick firm eventually added shipbuilding, the works quickly extending to seventy acres, and employing five thousand hands. Lord Armstrong, as president of the British Association in 1863, when it met at Newcastle, directed attention to the gradual reduction of our coal supply, and as a

result a Royal Commission was appointed, of which he was a member. He also did much to bring about an amendment of the Patent Laws. In 1887, the year of Her Majesty's Jubilee, he was called to the House of Lords. He was a past-president of the Institution of Civil Engineers and the Institution of Mechanical Engineers. He received the honorary degree of LL.D. at Cambridge in 1862, and that of D.C.L. at Oxford eight years later. Lord Armstrong was a Knight Commander of the Danish Order of the Dannebrog, of the Austrian Order of Francis Josef, of the Brazilian Order of the Rose, and a Grand Officer of the Italian Order of SS. Maurice and Lazarus. He was elected an honorary member of the Society of Engineers in 1889.

Dr. William Pole, whose death occurred on December 30, 1900, was born in Birmingham in 1814. He was brought up to the engineering profession, which he followed in the Midlands until 1844, when he was appointed professor of civil engineering in Elphinstone College, Bombay. He held that appointment for three years, after which he returned to England, and established himself as a consulting engineer. In 1859 he was appointed professor of civil engineering at University College, London. He was also lecturer to the Royal Engineer establishment at Chatham. He was a member of the committee on Iron Armour in 1861, and subsequently served on three Royal Commissions, namely, those on railways in 1865, on water supply in 1867, and the Thames pollution in 1882. In 1885 he acted as secretary to a committee on the science museums at South Kensington. In later times Dr. Pole was perhaps best known as the honorary secretary of the Institution of Civil Engineers, of which body he was a member for more than sixty years. He was appointed honorary secretary in 1884, on the death of Mr. Charles Manby. Dr. Pole wrote a life of Sir William Fairbairn, and a life of Sir William Siemens. He was a skilled musician, and took the degree of Bachelor of Music at Oxford in 1860 and that of Doctor of Music in 1867. Dr. Pole was elected an honorary member of the Society of Engineers in 1867.

ANNUAL REPORT OF THE COUNCIL, 1900.

In again presenting to the Members their Annual Report and the audited Statement of Accounts, the Council regret having to record the loss by death of a number of Members and Associates. Among the deceased Members are three distinguished Honorary Members, namely, M. Samson Jordan, the eminent French engineer and metallurgist, Lord Armstrong, the no less eminent hydraulic engineer and artillerist, and Dr. William Pole, who was a member of several Royal Commissions, and who held several Engineering Professorships during his life.

The Membership Roll.

The following statement shows the muster roll of the Society at the close of the year 1900, and the two immediately preceding years.

Class.	Dec. 31, 1898.	Dec. 31, 1899.	Dec. 31, 1900.
Honorary Members	20	20	18
Ordinary Members	237	246	246
Ordinary Associates	119	132	128
Foreign Members	68	69	64
Foreign Associates	32	33	30
Total Membership	476	500	486

The President's Badge of Office.

It is with extreme gratification that the Council have to record a special honour conferred upon the Society by the Honorary Secretary and Treasurer, Mr. George Burt, who has generously presented it with a President's Badge of Office, in gold and enamel, which is to be worn by the President for the time being at all meetings of the Society and on all public occasions upon which he represents the Society. The Council have pleasure in recording the high appreciation of this presentation by Mr. Burt, as expressed by the Members at the last Annual General Meeting of the Society. A reproduction from a full-size photograph of the badge forms an appropriate frontispiece to the present volume of Transactions.

M. Eiffel's Presentation.

The Council also have to place on record the presentation to the Society by M. Eiffel, the eminent French engineer, and the designer and constructor of the Tower bearing his name, of an exhaustive illustrated treatise on that triumph of engineering, the work being comprised in two large volumes, one being the text, and the other the plates illustrating in detail that remarkable structure. M. Eiffel has also presented to the Society a copy of his report on the scientific work carried out at the Eiffel Tower from 1889 to 1900. These volumes form a valuable addition to the library of the Society, where, with other works, they can be consulted by the Members.

The Council have to congratulate one of the oldest Members of the Society, Mr. John Aird, M.P., upon having had a baronetcy conferred upon him at the commencement of the present New Year. Sir John Aird was elected a Member of the Society in 1855.

The Council take this opportunity of urging all Members to do their best to induce their friends who are eligible, to join this Society, and thus, by increasing alike our numbers and our sphere of operations, to enlarge our opportunities of mutual assistance.

It may be as well to point out that the Society is not a specialised Institution, but that it admits to its ranks Members practising in all the varied branches of the profession, provided they are duly qualified.

Financial Position.

The Statement of Accounts for the year shows that the utmost economy has been exercised in regard to the working expenses, every item except Transactions and Secretary's Salary, being less than last year, in some instances very considerably so. The Transactions cost some 40*l.* more than in the previous year, but the Council feel satisfied that the extra bulk and the general quality of the matter contained in the volume fully justify the extra cost. The excess of income over expenditure, amounting to 52*l.* 17*s.* 3*d.* on the year, which is secured, notwithstanding the extra cost of the Transactions, shows that the financial resources of the Society are well maintained. The General Balance Sheet, showing the accumulated fund as 610*l.* 15*s.* 7*d.*, is also extremely satisfactory.

It will be interesting here to remind the Members that in 1897 the late Sir Henry Bessemer, in order to perpetuate his annual premium of 5*l.* 5*s.*, made over to the Society a capital sum sufficient for that purpose, which, together with the surplus funds of the Society, is invested in North Eastern and London and North Western Railway Stocks, in the names of the following Trustees, viz.:—Sir Benjamin Baker, K.C.M.G., Sir Douglas Fox, and Sir William Henry White, K.C.B., LL.D., F.R.S., on behalf of the Society. These gentlemen are all Honorary Members of the Society.

Papers Read.

During the year the following interesting Papers have been read at the Ordinary Meetings, and these, together with the discussions thereon, will render the forthcoming volume of Transactions a worthy successor to those which have preceded it.

1. The President's Inaugural Address. By Mr. Henry O'Connor.
2. The Closing of Breaches in Sea and River Embankments. By Mr. Richard F. Grantham.
3. Disinfection of the Maidstone Water Service Mains. By Dr. Sims Woodhead and Mr. William J. Ware.
4. The Economical Disposal of Town Refuse. By Mr. Brierley Denham Healey.
5. Notes on Electric Traction. By Mr. Algernon Hamo Binyon.
6. Paper-making Machinery. By Mr. Robert Henderson.
7. Notes on English and French Compound Locomotives. By Mr. Charles Rous-Marten.
8. Recent Practice in Sewage Disposal. By Mr. Henry C. H. Shenton.

The Council have awarded Premiums to the authors of four of these papers, viz.:—The President's Gold Medal to Mr. Henry C. H. Shenton; the Bessemer Premium to Mr. Richard F. Grantham; and Society's Premiums to Mr. C. Rous-Marten and Mr. Robert Henderson respectively.

The attendance of the Members at the ordinary meetings, although not all that the Council could desire, has maintained an average which, considering the ever increasing number of similar meetings, is satisfactory. The discussions have proved most interesting and instructive, and many of the most eminent men in the various branches of Engineering represented by the Papers read, have taken part in them.

Visits to Works.

During the past year three visits to engineering works have been made, and, judging by the numbers attending them, have proved of great interest to the Members and their friends. On June 20, the Thames Ironworks, Blackwall, were inspected by the kind permission of the Directors. H.M. ships *Duncan* and *Cornwallis*, first-class armoured battleships, which were in course of construction, were inspected, as well as the engineering departments of the works generally. About 70 Members and Associates were present.

On July 18, by the kind permission of the Secretary of State for War, a visit was made to the School of Gunnery at Shoeburyness, where the School and the experimental ranges were inspected. The Commandant, Colonel J. F. Bally, R.A., arranged a special pro-

gramme of experimental practice, which was carried out during the visit. By kind invitation of the Commandant and officers, Royal Artillery, the Members were entertained at luncheon at the Royal Artillery Mess. About 40 Members and Associates joined in the visit.

The third visit, which took place on September 26, was to the works of the Gas Light and Coke Company at Beckton, by the kind permission of Mr. T. Goulden, the engineer-in-chief. These are the largest manufacturing works of the Gas Light and Coke Company, producing about one-half the gas supplied by that company. The inspection proved highly interesting, a large number of Members again being present.

The Council take this opportunity of pointing out the great advantages which these visits to works offer to the junior Members, and of urging them to make it a regular practice to attend them. It is worth recording that to this Society belongs the credit of having initiated in 1862 the now general custom of including visits to works in the programme of Technical Societies.

Annual Meeting.

The Annual General Meeting was held at the Society's Offices on Monday, December 10, when the Members of Council and Officers, whose names appear on the first page, were elected by ballot in the usual manner. The Council desire to point out in this connection that while it is found most convenient that nominations for the vacancies occurring on the Council from time to time should emanate from the Council for the time being, any additional nominations made by ordinary Members of the Society always receive the most careful attention, and such nominations are invariably considered before any others in connection with succeeding balloting lists.

Annual Dinner.

The forty-seventh Annual Dinner took place on December 12, at the Hotel Cecil, when a large number of Members and their friends took part in this by no means the least important of our gatherings. A number of distinguished guests were invited, some of whom honoured the Society with their presence.

Exchange Transactions.

The Society continues to exchange Transactions with the Institutions named in the following list, and to receive periodicals from the editors of the leading technical journals which are available for the use of the Members and Associates :—

The Institution of Civil Engineers.
The Institution of Mechanical Engineers.
The Institution of Electrical Engineers.
The Institution of Naval Architects.
The Iron and Steel Institute.
The Surveyors' Institution.
The Civil and Mechanical Engineers' Society.
The Institution of Junior Engineers.
The Institute of Mining and Metallurgy.
The Royal Engineers' Institute.
The Incorporated Gas Institute.
The Royal Institute of British Architects.
The Society of Arts.
The Liverpool Engineering Society.
The Cleveland Institution of Engineers.
The North East Coast Institution of Engineers and Shipbuilders.
The North of England Institute of Mining and Mechanical Engineers.
The South Wales Institute of Engineers.
The Institution of Engineers and Shipbuilders in Scotland.
The Institution of Civil Engineers of Ireland.
The French Institution of Civil Engineers.
The Canadian Civil Engineers' Society.
The Victorian Institute of Engineers.
The Engineering Association of New South Wales.
The American Society of Civil Engineers.
The Association of Engineering Societies.
The Smithsonian Institution.
The Franklin Institute.

In conclusion, the Council desire to urge upon every Member the desirability of using his best endeavours to promote the interests of the Society at large by regular attendance at all the meetings, by securing as many new Members as possible, and by contributing Papers or taking part in the discussions as opportunity may offer. The younger Members especially are assured that every encouragement will be afforded to them in any effort they may make in this direction, and they are specially invited to submit papers upon subjects of current interest for reading and discussion at the ordinary meetings.

With adequate support from the general body of Members, the Council anticipate no difficulty in not only maintaining the prestige and usefulness of the Society as a whole, but in developing the same to the utmost possible extent.

January, 1901.

INCOME AND EXPENDITURE ACCOUNT FOR THE YEAR ENDED 31ST DECEMBER, 1900.

Dr. EXPENDITURE.	£	s.	d.	INCOME. Cr.	£	s.	d.
To Printing Transactions, *less* Sales	182	19	10	By Subscriptions for the Year (*less* irrecoverable)	630	8	0
,, Rent of Offices and Hire of Rooms	122	16	0	,, Life Subscriptions—proportion for 1900	10	12	0
,, Salary of Secretary	221	13	4	,, Admission Fees	46	14	6
,, Stationery and General Printing	26	0	6	,, Interest on Investment and Deposit	13	3	1
,, Reporting Meetings	14	14	0				
,, Refreshments for Members at Ordinary Meetings	7	15	8				
,, Fuel, Lighting, Office Cleaning and Repairs	14	1	4				
,, Postage, Telegrams, Carriage, and General Expenses	50	7	1				
,, Depreciation on Furniture	4	12	1				
,, Vacation Visits and Dinner—deficiency	3	0	6				
	648	0	4				
,, Balance carried to Accumulated Fund—Excess of Income over Expenditure for the year ended 31st December, 1900	52	17	3				
	£700	17	7		£700	17	7

LIFE MEMBERSHIP FUND.

	£	s.	d.		£	s.	d.
To Revenue Account—proportion for the year 1900	10	12	0	By Balance, being the unexhausted Balance of the Fund on 31st December, 1899	106	0	4
,, Balance to be carried to next Account	95	8	4				
	£106	0	4		£106	0	4

PREMIUM FUND.

	£	s.	d.		£	s.	d.
To Premiums	14	0	0	By Balance brought forward from 31st December, 1899	14	17	9
,, Balance to be carried to next Account	16	13	6	,, President's Donation	10	10	0
				,, Interest received from "Bessemer Trust" Investment	5	5	9
	£30	13	6		£30	13	6

BALANCE SHEET, 31st DECEMBER, 1900.

LIABILITIES.

	£ s. d.	£ s. d.
Sundry Creditors		3 7 10
Life Membership Fund		95 8 4
Premium Fund		16 13 6
Subscriptions Paid in Advance		21 10 6
Accumulated Fund:—		
Balance at 31st December, 1899	£557 18 4	
Add Excess of Income over Expenditure for the year ended 31st December, 1900	52 17 3	
		610 15 7
		£747 15 9

ASSETS.

	£ s. d.	£ s. d.
Cash at Bank and in Hand		37 12 7
Subscriptions in Arrear, *less* reserved for Bad Debts		96 2 6
Cash on Deposit	£300 0 0	
Investment—£166 L. and N. W. Ry. Co. 3 per cent. Debenture Stock	199 5 8	
		499 5 8
Office Furniture, Library and Stock of Transactions		114 15 0
		£747 15 9

Note.—£185 North Eastern Railway Stock is held in Trust to secure payment of the late Sir H. Bessemer's premium.

Audited and found correct,

SAML. WOOD, F.C.A.,

Hon. Auditor.

SOCIETY OF ENGINEERS.

INDEX TO TRANSACTIONS

1857 to 1900.

AUTHORS.

SUBJECTS.

LONDON: PRINTED BY WILLIAM CLOWES AND SONS, LIMITED,
STAMFORD STREET AND CHARING CROSS.